MARIE Skłodowska-CURIE ACTIONS

Innovative Training Networks (ITN)
Call: H2020-MSCA-ITN-2019

PART B

"The LHCnet"

This proposal is to be evaluated as:

ETN

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LIST OF PARTICIPATING ORGANISATIONS

Consortium Member	Legal Entity Short Name	Academic	Non-Academic	Awards Doctoral Degrees	Country	Department/ Division/ Laboratory	Scientist-in-Charge
Beneficiaries							
University of Minho	UM	✓		✓	Portugal	Physics Department	Onofre, António (coordinator)
University of Manchester	UMAN	✓		✓	United Kingdom	School of Physics and Astronomy	Peters, Reinhild (deputy-coordinator)
Vrije Universiteit Brussel	VUB	✓		✓	Belgium		D'Hondt, Jorgen
Transilvania University of Brasov	UTBv	✓		✓	Romania	Electronics and Computers Department	Ivanovici, Mihai
University of Freiburg	ALU-FR	✓		✓	Germany	Institute of Physics	Knue, Andrea
Palacky University	PU	✓		✓	Czech Republic	Faculty of Science	Kvita, Jiri
University of Copenhagen	UCPH	✓		✓	Denmark		Trott, Michael
Deutsches Elektronen-Synchrotron	DESY	✓			Germany		Meyer, Andreas
(Entity with a capital or legal link: University of Hamburg)	UHH	✓		✓			Gallo, Elisabetta
University of Coimbra	UC	✓		✓	Portugal	Physics Department	Oliveira, Orlando
Comenius University	UCOM	✓		✓	Slovakia		Tokar, Stano

Partner Organ.							Scientist-in-charge	Role of partner organization
CERN	CERN	✓			Intl. Org.	PH Department	David, André	Research, Training, Secondment
University of Torino	UniTO	✓		✓	Italy		Passarino, Giampiero	Research, Training, Secondment
University of Heidelberg	UHeid	✓		✓	Germany		Brivio, Ilaria	Research, Training, Secondment
University Autonoma de Madrid	UAM	✓		✓	Spain		Aguilar-Saavedra, Juan	Research, Training, Secondment
Bosch	Bosch		✓		Portugal	Car Multimédia Portugal, SA	Abreu, Sofia	Training Secondment

Data for non-academic beneficiaries

Name	Location of research premises (city/country)	Type of R&D activities	No. of full-time employees	No. of employees in R&D	Web site	Annual turnover (Euro)	Enterprise status (Yes/No)	SME status (Yes/No)
NOT APPLICABLE								

Declarations

Name (institution / individual)	Nature of inter-relationship
NOT APPLICABLE	

PROPONENTS

The LHCnet network is proposed by the following academics which are developing their scientific research work, together with their PhD students and Postdocs, in areas covered by the current proposal.

University of Minho team (Coordinator)
Scientist-in-charge: Antonio Onofre; Postdocs: Miguel Fiolhais; PhD students: Emanuel Gouveia, Bernardo Marques.

University of Manchester team (Deputy-Coordinator)
Scientist-in-charge: Reinhild Peters; Postdocs: James Howarth, Yang Qin; PhD students: Callum Birches-Sykes, Nicolas Scharmberg;

Vrije Universiteit Brussel team
Scientist-in-charge: Jorgen D'Hondt; Postdocs: Kirill Skopven, Petra Van Mulders; PhD students: Seth Moortgat, Emil Bols;

Transilvania University of Brasov team
Scientist-in-charge: Mihai Ivanovici; Postdocs: Radu-Mihai Coliban; PhD students: Stefan Popa.

University of Freiburg team
Scientist-in-charge: Andrea Knue; Additional supervisor: Prof. Gregor Herten; Postdocs: Zuzana Rurikova; PhD students: Manuel Guth;

Palacky University of Olomouc team
Scientist-in-charge: Jiri Kvita; Postdoc: Karel Cerny, Rostislav Vodak, PhD students: Petr Baron, Josef Pacalt;

University of Copenhagen team
Scientist-in-charge: Michael Trott; Postdocs: T. Corbett, J. Talbert; PhD students: A. Helset, A. Barzinji, A. Vasudevan;

DESY team
Scientist-in-charge: Andreas Meyer; Co-Supervision: Elisabetta Gallo (Hamburg U./DESY); Postdocs: Mykola Savitskyi; PhD students: Joscha Knolle, Valerie Scheurer;

University of Coimbra team
Scientist-in-charge: Orlando Oliveira; Postdocs: João Moreira, Márcio Ferreira, Paulo Silva, Pedro Costa, Violetta Sagun;

Comenius University team
Scientist-in-charge: Stano Tokar; Co-Supervision: Pavol Bartos; Postdocs: Tomas Dado, Michal Dubovsky, Oliver Majersky; PhD students: Dominik Babal, Barbora Eckerova, Michal Racko;

1. Excellence

1.1 Quality, innovative aspects and credibility of the research programme

1.1.1 Introduction, objectives and overview of the research programme

The principal objectives of the LHCnet scientific research program are:

- Develop and implement a new generation of global data analysis, across different LHC experiments and several physics groups from each experiment, based on the sharing of RooFit workspaces.
- Reduce the global systematic uncertainties affecting the LHC measurements.
- Perform global fits of top quark, Higgs boson, and EW properties, within the context of SMEFT, in a rigorous and model-independent way.
- Extract the maximum potential of the physics at the LHC, both in Run 2 and Run 3.
- Train a new generation of leaders for both academia and the non-academic sector.

The current proposal aims to build a European Training Network (the LHC network, or “LHCnet” for short) that will provide training in data analysis methods, across several physics research groups within experiments which are currently taking data at the Large Hadron Collider (LHC), ATLAS and CMS. To ensure the highest training level for the Early Stage Researchers (ESRs), they will be involved in international research programmes of the highest scientific quality with state-of-the-art techniques applied on High Energy Physics (HEP), as is typically the case of the programmes of those experiments. The ESRs will be exposed to instrumentation and detector development aspects associated to building complex particle physics experiments, to become future experts on HEP, in a broader and integrated way. The LHCnet aims as well to make sure the skills and expertise developed by the ESRs during the course of the current programme, are bridged to society and to the industry, by challenging the ESRs with concrete industrial problems and through dissemination with a dedicated outreach program.

The LHCnet proposal involves established experts, from several institutions, with strong expertise in Particle Physics and who belong to research groups with bridges to Astrophysics and Astronomy, from both the experimental and theoretical points of view. The need to develop such a network relies on the fact that testing the current Standard Model (SM) requires a dedicated joint effort from several communities (theoretical and experimental) in order to achieve the ultimate precision in testing the SM as expected for present and future colliders[1]. The potential of the LHC to perform very precise and sensitive measurements is by now confirmed, without a doubt. Following the discovery of the Higgs boson[2] by ATLAS and CMS, the measurements of top quark and Higgs boson properties have achieved an unprecedented level of precision, at the percent level, for several process cross sections and distributions. The versatility of the LHC experiments, together with the progress of theoretical calculations, has made a deeper interpretation possible, via the reduction of overall uncertainties in the data. These facts set the backdrop for the LHCnet, which aims to train ESRs with state-of-the-art methods and techniques in data analysis, to extend these further in order to perform a global analysis of data acquired by ATLAS and CMS, profiting as well from the available Monte Carlo simulations, from different generators and experiments. This necessarily implies the involvement of researchers from institutions which are strongly committed in ATLAS and CMS. It is sensible at this point to note that precision measurements are an essential complement of a direct search program for New Physics Beyond the SM (BSM), in the forms of either new particles or new interactions. The possibility that the energy scale associated to BSM is much higher than the centre-of-mass energies available at current colliders is a serious concern. This reason alone motivates the individual research programmes that

[1] **“The physics potential of HL-LHC”** (input to the European Strategy Group, ESG), https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCWorkshop, WG1 and WG2 reports.
[2] ATLAS Coll., Phys. Lett. B 716, 1 (2012), arXiv:1207.7214; CMS Coll., Phys. Lett. B 716, 30 (2012), arXiv:1207.7235.

experiments have pushed forward, in what concerns deviations from the SM. Probably the most remarkable historical examples of the interplay between direct and indirect measurements have been: the proposed existence of the charm quark (in the lack of any evidence for Flavour Changing Neutral Currents - FCNC), the prediction of the top quark mass (indirect limits of which set the order of magnitude quite accurately), or the recent discovery of the Higgs boson. The precise determination of the properties of these two fundamental particles, their role in the meta-stability of the Universe, and the connection to the Electroweak Symmetry Breaking (EWSB) mechanism are among the primary targets of the LHC programme, which will be extended to the High Luminosity phase (HL-LHC). It is central to the LHCnet to perform the best possible training to prepare ESRs for these challenges and to allow them to develop their own future careers, either in academia or in the non-academic sector, taking profit from the skills and knowledge developed during the training period.

The proponents have been involved in top quark and Higgs boson research programmes of both ATLAS and CMS (and previously in the CDF and D0 experiments at the Tevatron, Fermilab) since a long time, as well as in detector development programmes. They have been key persons in establishing the LHC experiments scientific programs, acting either as conveners of the Top Quark and Higgs boson groups (and sub-groups) of the experiments or chairing several committees within the experiments or in bodies that interface with theory. They have also assumed leading roles in their home institutions as responsibles for research programs, research groups, Directors of scientific institutions or even being members of European committees or chairing those committees. The team has a strong expertise in data analysis methods and tools applied to HEP, and also in developing detectors for collider experiments and associated instrumentation. By pushing forward a proposal for a new network, the LHCnet, the proponents intend to extend the very successful past experience of the individual research groups working in either ATLAS and CMS, to the next level, where information is shared in a global way, across the different experiments and research groups. This is accomplished by exchanging RooFit workspaces, that reflect the four-momenta phase space of the selected events by both ATLAS and CMS, including the effects of signal/background modelling, the data and systematic uncertainties parameters used to construct the likelihoods for the global fits, as is done in present Higgs analyses. In this way, the simultaneous interpretation of the data collected by ATLAS and CMS is done together, in a global way, joining distributions from both experiments in one consistent analysis programme. Definition of event topologies and selection criteria, analysis development and validation, statistical and systematic uncertainty studies (including theoretical uncertainties), development of complex multivariate type of analysis, including the use of evolved tools like Deep Neural Networks or other Machine Learning tools, are areas where European (EU) scientists are world-leading. The LHCnet intends to build a training program for ESRs based on the knowledge and leadership of EU scientists, to further develop and explore new tools for data analysis, that will allow to perform global fits of data, from different experiments, and across different research groups (top quark and Higgs boson groups, progressively extending to the Electroweak and flavour sectors of the SM), within each experiment. The current LHC shutdown for a couple of years, before the RUN 3 starts, is particularly timely to start such a network, giving ESRs the possibility of being trained with RUN 2 data, and prepare them for the future RUN 3 of the LHC, and future collider programmes ahead. At the same time, the European Strategy for Particle Physics is being reviewed.

In January 2010, a joint effort between ATLAS, CMS, and the theory community created the LHC Higgs Cross Section Working Group (LHC Higgs XSWG), aiming to produce common predictions for cross sections and branching fractions, and common definitions of pseudo-observables relevant to the SM Higgs boson studies performed by ATLAS and CMS. The scope of this group was enlarged in 2012 to include studies of Higgs properties and BSM scalar searches. Also in 2012, a LHC Top Physics Working Group (LHCTopWG) was set up to define guidelines for the combination of results on top quark physics from ATLAS and CMS, and eventually extend to the Tevatron results for world combinations, such as for the top quark mass determinations. These two groups, viz. the LHC Higgs XSWG and the LHCTopWG, set the appropriate environment to develop the training programmes of the LHCnet network, once exchanging information is possible and encouraged, subject to the confidentiality requirements stated in both groups mandates. **The training of the ESRs** on the global fits of data, and their progress reports, **is expected to be performed within the LHC experimental collaborations as well as in the LHC Higgs XSWG and LHCTopWG.** The groups are the right choice for such reports, as they constitute open forums where all interested parties are invited to contribute to the groups global effort. Since the proponents have strong experience on being involved in both groups, either as conveners from ATLAS and CMS, or by being directly involved in the measurements of top quark and Higgs boson properties, like the mass, the couplings, the production cross sections and decay branching fractions, as well as searches for BSM in decay channels involving final state topologies that include top quarks and/or Higgs bosons, it is natural to fully explore the potential of the significant increase in luminosity expected for the LHC RUN 3. Given the progress on the analysis tools and methods, and better control of systematic uncertainties expected from the global fits which, in addition, allow access to intrinsic correlations between measurements and nuisance parameters which otherwise are difficult or even impossible to estimate, **the LHCnet aims for a significant improvement on the precision with which SM measurements are performed at the LHC.** The interplay between the different experiments and the theoretical communities is crucial to assure the necessary knowledge transfer to perform an accurate and precise interpretation of data. This is particularly important for the LHCnet and the training programme, given that a rigorous SM Effective Field Theory (SMEFT) model-independent framework is expected to be used in the EW and Higgs boson, as well as top quark data interpretation. Precision measurements are an important tool to search for BSM, in particular if the associated mass scales are far too high for direct detection at the LHC. In this case, exploiting possible effects of BSM on processes at lower energies via virtual effects is indeed a promising approach, and will be used during the full lifetime of the LHC, including the HL-LHC phase[3]. It is thus important that the training programme covers the necessary theoretical foundations and tools so as to allow them to understand the fundamental theory aspects, the effects of the different dimension-6 operators on physics processes and the constraints on Wilson coefficients when interpreting the data, following a global approach. The LHCnet intends to provide training of ESRs from both ATLAS and CMS on the use of SMEFT tools and interpretation, in a model-independent framework that extends the current knowledge of the SM in all directions consistent with quantum field theory (QFT), making it a perfect and powerful agnostic training framework. **Figure** 1 shows a schematic representation of the training concept. From the common theoretical framework, with predictions for relevant top quark and Higgs boson observables, to a global analysis and SMEFT interpretation, the training process goes through ATLAS and CMS optimized analyses, adjusts them to build the global analysis, and then performs the simultaneous fit to all the data.

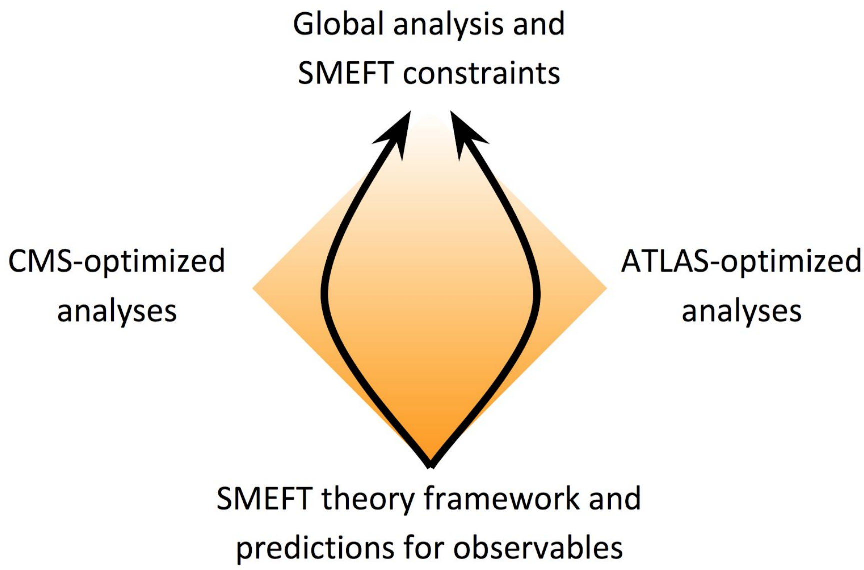


Figure 1. Schematic diagram representing the scientific research skeleton behind the network: starting from a common theoretical framework, continuing with ATLAS and CMS optimized analyses, arrive at SMEFT constraints from a global analysis.

[3] M. Cepeda, S. Gori, P. J. Ilten, M. Kado, and F. Riva, (conveners) *et al.*, ***Higgs Physics at the HL-LHC and HE-LHC***, CERN-LPCC-2018-04, https://cds.cern.ch/record/2650162; Juan Antonio Aguilar-Saavedra (ed.) *et al.*, ***Interpreting top-quark LHC Measurements in the Standard-model Effective Field Theory***, CERN-LPCC-2018-01, arXiv:1802.07237; D. de Florian *et al.*, ***Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector***, LHC Higgs Cross Section Working Group, FERMILAB-FN-1025-T, CERN-2017-002-M, arXiv:1610.07922; G. Passarino and M. Trott, ***Standard Model Effective Field Theory and Next to Leading Order***, arXiv:1610.08356; B. Grzadkowski, M. Iskrzynski, M. Misiak, and J. Rosiek, ***Dimension-Six Terms in the Standard Model Lagrangian***, JHEP 10 (2010) 085, arXiv:1008.4884.

The long-term goal of setting up now a culture (and appropriate tools) for the HL-LHC phase, is a purpose of this network, by using the ongoing shutdown of the LHC (LS2) during 2020 and part of 2021 as preparation ground, and the LHC RUN 3 as a stepping stone. Bridging the analysis methods and techniques applied to Higgs boson studies (based on RooFit workspaces and simultaneous analysis) and top quark measurements (including differential distributions used in global fits), which are performed by different communities, in a global way across the LHC experiments, **allows to set up a unique environment for the ESRs training, which will**:

1. **Start by developing and learning a common SMEFT** theoretical and simulation framework,
2. **Go to their own experiments** (ATLAS and CMS) **and perform the best-possible analysis** given the strengths of their respective detectors, in their sector choice (Higgs, top, etc.), and
3. **Meet back for a common and simultaneous analysis of the data from both ATLAS and CMS, across different sectors** (Higgs, top, etc.).

The results are then expected to be reported back to the LHC Higgs XSWG and the LHCTopWG, in addition to ATLAS and CMS groups from the partners. As is implied from the nature of the current proposal, **the LHCnet intends to integrate the individual projects of the recruited ESRs in the global fit,** by taking the individual contribution of each ESRs best-possible analysis developed in their own experiments (ATLAS and CMS) and integrating this work in the common and overall simultaneous analysis which will lead to the final global fit. It is foreseen that, during the training period, the different ESRs will provide information and results at different moments in time. This is not considered a major constraint, since the intrinsic nature of the training network of the LHCnet proposal is to incorporate contributions from the ESRs in the global fit as they become available.

A significant number of measurements performed during RUN 2 are limited by systematic uncertainties. Although the increase of luminosity from RUN 1 to RUN 2 was in itself a great achievement for the LHC machine, it benefited a lot the experiments, allowing them to deeply understand the experimental conditions in which data-taking was performed. Nevertheless, new strategies need to be developed to further reduce the systematic uncertainties. Moreover, **it would be quite interesting to understand the overall correlations among the measured fundamental SMEFT parameters, which are naturally accessible in a global analysis of the data, as envisaged by the LHCnet.** While other networks are developing strategies to reduce the overall uncertainties in theoretical predictions and signal modelling dependencies (by providing new state of the art calculations at higher orders in QCD+EW or Monte Carlo generators tuned to data), the LHCnet intends to reduce the systematic uncertainties by integrating, as much as possible, the full set of interesting signals from top quarks, Higgs boson and EW physics, into one common and simultaneous analysis. It is extremely important that the ESRs to be recruited understand all the details of the individual analysis they are working on in their own experiments, ATLAS and CMS, to allow the integration of such analysis into the global analysis later on.

There are two significant periods of time considered in the LHCnet proposal. **The first one runs during the ongoing LS2 shutdown of the LHC**, until mid-2021, and corresponds to the preparation phase of the trainees, when they are exposed to the most up to date analyses in ATLAS and CMS. During this period the full data-set collected by both experiments during RUN 2 will be exploited. The ESRs will perform the best measurements possible and learn to interpret their results within the SMEFT framework. If no direct evidence for BSM is found in the RUN 2 full data set, the emphasis on precision measurements and indirect searches through top quarks, Higgs bosons and EW processes, becomes particularly relevant, as do the SMEFT fits themselves. **The second period starts with the beginning of the LHC RUN 3** data-taking (mid-2021 to the end of 2023), with an increased centre-of-mass energy (14 TeV) and higher luminosity. In this period, the knowledge and expertise acquired among the trainees of the LHCnet will allow to further extend the activities to the analysis of the new data that will become progressively available in ATLAS and CMS.

Over the past few years, **the contributions of the proponents of the LHCnet to the top quark and Higgs physics advances have been major** in high precision measurements and searches for BSM. Examples of measurements particularly relevant for the current proposal include: **the first measurements of the W-boson polarisation** and the search for new couplings at the Wtb vertex; **the search for rare top decays through FCNC** which indeed used for the first time a global analysis; **the measurement of Higgs boson properties (mass, decays, couplings)** and the interpretation of the couplings in terms of the SMEFT. From the theory side the contributions are also remarkable. Members of the LHCnet have been directly involved in **the definition of the SMEFT framework to interpret top quark and Higgs boson measurements**, as well as proposals to study **multi-boson production** at the LHC and **searches for multi-messengers** in a quest for signs of BSM. The knowledge and expertise acquired by the members of the LHCnet was recognized by their nomination to leading roles in both ATLAS and CMS, as conveners of top quark and Higgs boson analysis groups or subgroups. These responsibilities allowed to shape the research programs of the LHC experiments, in the areas relevant for the current proposal. This experience is considered of utmost importance in shaping the goals of the LHCnet.

The first step is to define signal regions according to the multiplicity of the specific type of objects existent in the selected events, e.g. the number of isolated charged leptons, the number of jets from the hadronization of light- and b-quarks (b-tagged jets), and the missing energy/momentum (associated to particles that are not detectable, like neutrinos). The unique approach relies on the conjugation of the relevant observables (mass distributions, differential cross sections, angular distributions, etc.) into one single global analysis, where each observable is studied for the particular choice of signal region under scrutiny. This is in contrast to methods that combine results from different analyses, each one with its own separate list of sources of systematic uncertainties. **In the LHCnet, the analysis strategy aims to perform a simultaneous and global fit of the SMEFT parameters.** This allows to have access to correlations and blind directions not resolved by the data. This approach is considered of great importance to directly address the biggest problem of most precision measurements at the LHC: systematic uncertainties. While **the theoretical community has made significant steps in the definition of a global framework**, establishing basic common standards for a model independent and rigorous interpretation of top quark, Higgs boson and EW measurements within the SMEFT context, the experimental community still lags behind. **The LHCnet is a first attempt to perform such a global analysis approach, both across physics processes and experiments.** This initiative is the experimental equivalent of the initiative already undertaken by the theoretical community. It will profit from the interplay between theorists and experimentalists in order to identify the most sensitive observables in the search for BSM. **Modern Machine Learning (ML) techniques will be explored to define signal regions**, without necessarily relying on rigid selections on objects properties. Similar ML techniques will also be employed for full event reconstruction. Their applications can be extended to other domains of science and spread to society, establishing a natural bridge with **industry, which can profit directly from the use of ML techniques** in their production plants. Thus, the current proposal aims to build the LHCnet with the objective of preparing and training ESRs to become part of a new generation of leaders that may strengthen research groups or strengthen teams in industry and develop the necessary skills to lead their own research programs and groups in academia or industry.

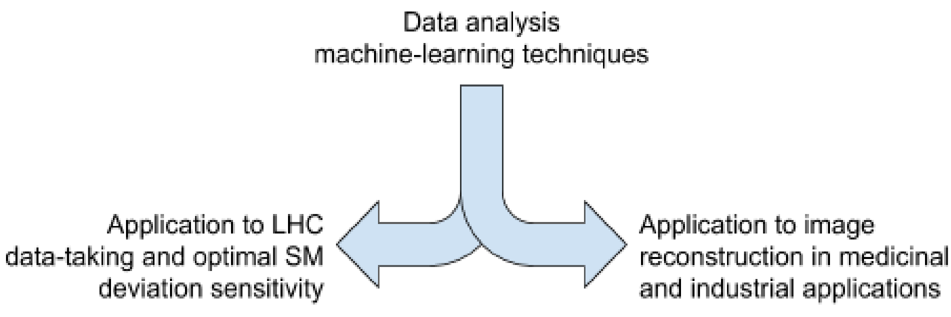


Figure 2. Schematic diagram representing the interaction between the research work and industrial applications.

One crucial aspect related to data analysis is the availability of competent human resources, who can perform demanding tasks, such as the development, maintenance and even user support for the tools used in the full analysis chain, i.e. from the event reconstruction up to the final physics result. **These require not only physics but also software and interpersonal skills.** There is a systematic shortage of skilled people, that are actually prepared to perform such tasks in both ATLAS and CMS, across several physics groups. The maintenance, development and support is many times dependent on very few people. **One of the main objectives** of the LHCnet network **is precisely to address this lack of expertise and train ESRs in the tools and techniques needed for effective data analysis.** These skills are easily transferable to non-academic applications in industry and society at large. **Partners of the LHCnet network have experience in close collaboration with industry.** One example is the collaboration with Bosch. In November 2016 a cooperation Protocol (iSci-Bosch-ECUM) was signed between

Bosch Car Multimedia Portugal, S.A. and the University of Minho. The parties showed interest in developing a partnership to create synergies in the areas of investigation and technical development (I&TD), training, internships and other activities. Cooperation proceeds via Collaborative Activities (CA) including (but not limited to):

- Identifying the activities that are particularly interesting for both parties;
- Identifying workers/researchers from both parties in charge of monitoring the various activities;
- Establishing a work plan and the respective schedule, for each CA;
- Monitoring the CA with regular meetings and
- Contributing to the evaluation process.

Under the above Protocol, a specific contract was signed between the parties for each CA. One CA example is that on “Optical Bonding”, part of the production of instrumented display panels for the car industry. This CA involved the development of optical monitoring systems (hardware and software) that was installed in the Bosch production lines, with the objective of extracting defective displays during the manufacturing process. After the 2017 development phase, the installation phase followed, with two of such systems fully operational since March 2018 in the Bosch production lines. During the course of the project, the human resources involved and trained through internships at Bosch, **five students at MSc and PhD levels, were hired by Bosch immediately after the end of the internship.** This type of activities will be encouraged within the network, providing the ESRs with training in concrete industrial problems, through internships in the industry. In the foreseen Annual Schools, the performance, training, and employability of the ESRs, as well as the research techniques which are relevant for the industry, will be discussed; more details are given in **Sections 2.1** and **3.1.1**. The Detector Panel of the European Committee for Future Accelerators (ECFA), compiled recently during 2018, a survey on Detector R&D[4]. Students and Postdocs feel that they lack knowledge in electronics, mechanics, software, and instrumentation already at the University level, which usually have insufficient training programs. Moreover, while detector technologies normally bring prominent visibility of particle physics in society, technology transfer from detector developments to applications for the wider society usually see insufficient support from institutions. **Exposing the ESRs to concrete industrial problems, solved with technologies typical of those used in particle physics experiments, helps closing the gap between academia and detector applications.**

In order to accomplish the interplay between the scientific research program and the industry, particular attention will be devoted to the ML techniques to be developed in the LHCnet, which will help the industry with significant impact in the production plants. The Beneficiaries of the LHCnet have extensive experience in developing optical systems to perform identification of displays with defects to be removed from the production line while in production. Although defective displays are at the level of 1 to 2%, the total number of displays produced is of the order of thousands per day (per line), which significantly impacts the amount of losses. Given the fact the diagnostic devices developed are presently completely integrated in two production lines and are performing with an efficiency around 95% for the identification of defects and 1% of false positives, their use was extended to eight other products , to detect several different types of defects, requiring the development of specific and dedicated software algorithms and packages for efficient diagnostic. These eight packages are expected to be replaced by the ML packages developed in the LHCnet. The identification of defects, from the point of view of the industry, does not require the full reconstruction of the defect, but just a learned decision whether the display has a defect or not. This will be accomplished by using ML techniques, given the variety of defects already under scrutiny. **The identification of such defects is a similar problem to that of physics signal discrimination that will be developed for the scientific program.** As pattern recognition is at the core of the problem, the techniques and tools developed by the network can be widely applied in other domains, in which images encode the properties of problem, e.g., biological systems in Biophysics.

A particularly important aspect of the network is the dissemination of the results obtained throughout society, as well as sharing the experiences of the ESRs (during the course of their daily research activity), with young people. Particle Physics is one of the scientific areas that catches the attention and imaginary of the general public. The Higgs boson discovery in 2012 is just one example of that. **The LHCnet will contribute to strengthening the public’s perception of fundamental science and its applications,** in order to attract young students and help them realizing science is an extraordinary tool to fulfill their own future expectations.

In order to accomplish the dissemination of results throughout society, the LHCnet intends to launch the initiative **"LHCnet ROCKS - LHCnet Reach Out, Connecting Knowledge and Scientists"** with two different

[4] ECFA Detector Panel Report, https://ecfa.web.cern.ch/sites/ecfa.web.cern.ch/files/ECFA_detector_panel_ESPPU_input_Dec2018.pdf

types of activities. A first type are Public Sessions during the proposed Network Events, targeting the general public and wide audiences. In these sessions, invited speakers (internal and external to the network) will share their expertise in domains relevant to the network or directly related to it (Particle Physics, Astroparticle Physics, Astronomy and Cosmology, etc.), as judged appropriate. In addition to these events, there will be a second type of activities that will bring together LHCnet researchers and the general public. This will be a series of video-conferences from the Network. These are oriented to the general public and high school students. In the era of communication technology, not only knowledge can be shared between scientists and high school students from different countries with complementary backgrounds, but also their experiences, and the choices and opportunities that their worldwide careers are made of. While the first type of activity is more effective for the local organizer audiences where the network events happen, the second type is broader and involves LHCnet groups and schools from different countries. These second type of activities are expected to happen once a year, and involves (at least) pairs of participating organisations: on one end researchers from a participating organisation are chosen to share their knowledge and career path with young students from another. These video sessions will be recorded and made available to the network and more widely. Further details are given in **Section 2.4**.

1.1.2 Research methodology and approach

The research methodology involves sharing expertise and information among researchers belonging to different Institutions, participating in different LHC experiments (ATLAS and CMS), and theory. This shared information has the central objective of allowing to perform a global fit to data acquired by both ATLAS and CMS, as a preparation for the RUN 3 of the LHC. The approach developed in this proposal is a generalization of the one used in the search for FCNC in *tZq* processes by CMS[5], by simultaneously using events from top-antitop quark paris and single top production in one single analysis of multilepton final states. This methodology was recently applied in ATLAS for the study of the structure of the *Wtb* vertex, which involved reconstructing events from top anti-top quark pair production and single top quark production through the t-channel and *Wt* associated production. The final states of all channels involve different numbers of isolated leptons (1, 2, and 3 or more), jets in different rapidity acceptance regions and different transverse momentum. It looks therefore quite natural, as a first milestone of the project, to combine both analyses from the two experiments into one single global analysis, where each signal region (SR) is identified against several background (BR) and control (CR) regions, according to the acceptance of the different objects used in the event selection (isolated leptons, jets, b-jets, missing transverse energy, etc.). The goal of such an approach is to perform a SMEFT fit, with the underlying Wilson parameters, without performing the measurement of intermediate observables, that have normally been combined to extract the SM parameters and used to probe the presence of BSM effects. This approach will be progressively extended to other rare top-quark production processes like the production of 4 top-quarks, the associated production of top quarks and Higgs bosons, and the Higgs sector, as a whole. For each of the signal regions, several observables are to be reconstructed using either kinematic fits or ML techniques, specifically designed to identify a given number of top quarks, *W* and *Z* bosons and also Higgs bosons decaying to several final states. **The interplay between theory and experiment is crucial to achieve the best precision possible** from state of the art theoretical calculations for the normalization cross sections used for the different processes, as well as for the angular and differential distributions identified as relevant for each of the signal regions. Each ESR is expected to contribute to the global analysis with one or more signal region studies. While in the end all signal regions will be used in the global fit, each signal region should be also fitted individually to compare the actual performance of the individual analysis with the results obtained with the global fit. **The methodology used to achieve this goal involves several phases** during the ESRs training period.

Firstly, the hired ESRs will start by learning the common SMEFT used to obtain predictions for the top quark, Higgs boson, and EW properties of the signals under study. **ESRs will also learn about Monte Carlo techniques for the simulations** needed in the whole analysis process. This will allow the ESRs to get a clear picture of how to perform the generation and simulation and have a critical look at the choice of the fundamental parameters used by the generators. The training will focus on the most common generators used in high-energy physics (Pythia, Herwig, Sherpa, MC@NLO, MadGraph, and Powheg).

Secondly, the experimental ESRs will work in their respective collaborations to perform the analysis of

[5] Isis Van Parijs, *"**Search for tZq Flavour Changing Neutral Currents in top production and decays with the CMS experiment**"*, http://website.iihe.ac.be/sites/default/files/thesis-isis-van-parijs-cms-master-2018pdf/

well-defined distributions, directly related to sensitivity to parameters involved in the global fit. These distributions concern:

1. The measurements of the top quark and Higgs boson masses;
2. The measurement of the production cross sections of top quarks (double and single top-quark production through the *t*, *Wt*, and *s* channels);
3. Measurement of angular distributions in those channels (W-helicity in all channels, Normal and Transverse polarization angles in the single production channel, as well as top quark polarization exploring single, double and triple differential distributions);
4. Measurement of rare top quark production (4 top-quarks) and rare decays (through FCNC);
5. Higgs boson production in association with top quarks (*tH* and *ttH*) in multilepton final states and explore spin correlations and the CP nature of the top quark Yukawa coupling, in the bosonic and fermionic sectors, separately.

The hired ESRs are expected to perform the best-possible analyses, profiting from the strengths of their respective experiments.

Thirdly, the ESRs are expected to adjust their analysis to the global analysis envisaged, given the expertise acquired in the second phase, by sharing RooFit workspaces, across different physics sectors, using all distributions, from both experiments. In this way all the work from all ESRs is naturally included in a global analysis, where each distribution is fitted to by SMEFT predictions, simultaneously. A particularly important aspect relates directly to the sharing of information among different LHC experiments and theorists. Following the discussion with the Physics Coordinators together with the management of the experiments, no show-stoppers have been identified that would made the current proposal impossible, using the LHC Working Groups (LHC Higgs XSWG and LHCTopWG) as places for sharing information in the form of RooFit workspaces between experiments. The training methodology just discussed above is represented, schematically, in **Figure** 3.

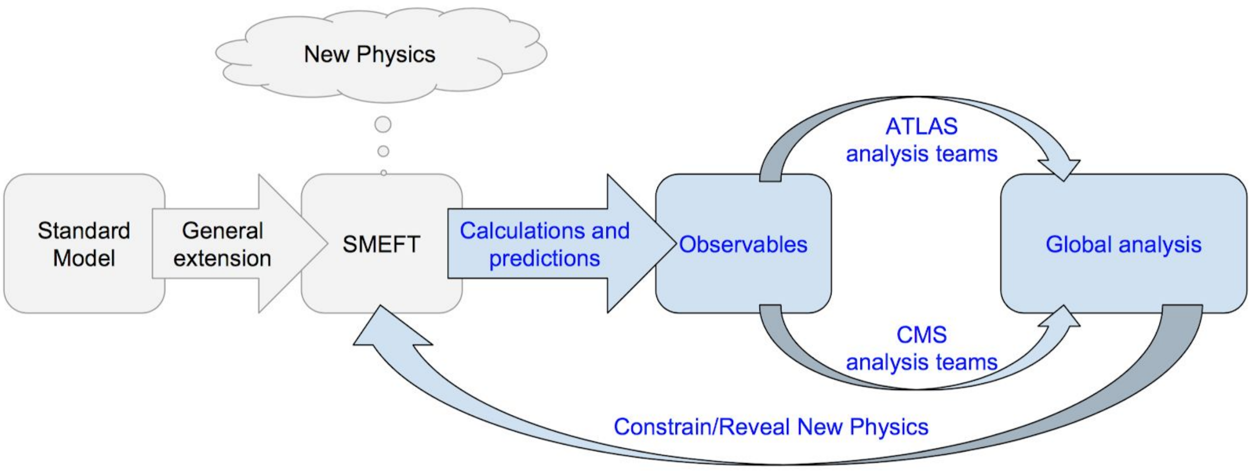


Figure 3. The training methodology: from learning the theoretical framework associated to calculations and predictions for interesting observables (first phase), passing by the analysis performed within ATLAS and CMS (second phase), to a global analysis used to test the SM and search for BSM.

One particularly important objective of the LHCnet is to also train ESRs in detector R&D and related instrumentation, needed for present and future high-energy physics experiments at present and future colliders. As this is also important for wider applications through society, a specific training program was developed, to allow the hired ESRs to acquire both the necessary skills for detector development and participate in projects in industry.

Table 1.1 describes the Work Package (WP) list for the LHCnet network. The associated research teams include active and experienced scientists that have been developing analysis tools and instrumentation for several applications, tools and detectors in HEP.

The WPs are listed in **Section 3.1.1**. In the remainder of this section a detailed description of the WPs. The individual ESRs projects, only briefly mentioned here for consistency, are described in more detail in **Section 3.1.4**. The inter-project activities are, however, described here, to highlight the interplay among all projects and the synergies developed among them and the WPs they relate to. **WPs 1-5 are the main research activities of the network and WPs 6-11 the main training activities with networking as well. WP 12 is dedicated to the management of the network.**

Table 1.1: Work Package (WP) list, assuming a start date of January 2020

WP No.	WP Title	Lead Beneficiary	Start month	End month	Action Type*	Lead Beneficiary	ESR involvement
WP1	Theory in a Nutshell Approach	M. Trott	M1	M48	T/R	UCPH	All
WP2	The LHCnet Global Analysis	A. Onofre R. Peters	M1	M48	T/R	UM UMAN	All
WP3	The LHCnet Machine Learning Program and Society Interface	A .Knue	M1	M48	T/R/D	ALU-FR	All
WP4	The LHCnet Hardware and Image Processing	M. Ivanovici	M1	M48	T/R	UTBv	All
WP5	Inter-Project Activities	A. Meyer	M1	M48	T/N/D/R	DESY	All Long-Term
WP6	Long-Term ESR training	J. D'Hondt	M1	M48	T/M	VUB	All Long-Term
WP7	Short-Term Studentships	M. Trott	M1	M48	T/N/M	UCPH	All Short-Term
WP8	Network Meetings	J. Kvita	M1	M48	T/M/N/D	PU	All
WP9	Outreach Activities	A. Knue	M1	M48	T/D	ALU-FR	All
WP10	Non-Academic secondments	R. Peters	M1	M48	T	UMAN	Long-Term ESRs
WP11	Annual Schools	S. Tokar	M1	M48	T/M	UCOM	All
WP12	Network Management	A. Onofre	M1	M48	M	UM	

* T: Training, M: Management, N:Networking, D: Dissemination, R: Research

The WP1 "Theory in a Nutshell" main objectives are to review the status of the SM, in what concerns the level of precision of measurements of absolute rate production cross sections, differential distributions, angular distributions, etc. and develop the SMEFT framework for the simultaneous fit performed to the observables. Precision measurements require a well-established theoretical framework, the Standard model (SM) being its low-energy limit. The SM has been extremely successful in describing the data acquired by experiments so far. With the discovery of the Higgs boson at the LHC, a key milestone was achieved in terms of the SM consistency. Although the discovery was undoubtedly important, the precision with which observables are calculated needs to reach the next level of precision on predictions (NLO+NNLL, NNLO, NNLO+NNLL, etc) if the understanding of possible deviations seen in data are clear manifestations of BSM at an energy scale which does not allow the direct detection of massive particles or new interactions. BSM indirect searches for multi-messengers is simply a need of present times. Given the fact that we live in a Universe which is 95% unknown to us, the question is not if there is anything new, but what it is, and if the impact of new particles and/or interactions on observables measured experimentally can be probed in a global analysis of the data available. The WP1 has two main components:

1. Revisit the actual status of the SM theory and check the contributions of higher order corrections for top and Higgs production at the LHC. This includes the NNLO+NNLL contributions that, at the moment, are evaluated in $tt+X$ production ($X = \gamma, Z, W, H$) and the many observables under study in this network;
2. Identify the relevant operators and develop the SMEFT framework that can be probed within the multi-messengers physics signals studied in the LHCnet.

The list of operators is quite large already, and the strategy of the network would be to progressively include more and more operators in the fit, in a global approach, starting with top quark production (tt, ttW, ttZ, $tt+\gamma$, ttH, 4-top, and single top, etc.), including the Higgs sector, and Electroweak processes in general (W and Z physics) covering different final states of the decayed heavy particles. **The individual project of ESRs in WP1**, long-term students, is associated to the implementation of these tasks. In performing the global fit of data, guidance on which is the level of precision, and type of observables most sensitive for a SMEFT global fit, is mandatory. At the end of the project, clear guidance should be made available to all partners of the network.

The WP2 "The LHCnet Global Analysis" main objective is to perform a global analysis of data, using different signal regions and different LHC experiments, in one go. Precision measurements also require new data analysis strategies for the LHC. The fact that systematic uncertainties are dominant in many measurements, implies that new strategies are needed. Instead of combining analysis results using their statistical and systematic uncertainties, with possible correlations either forgotten or too conservatively estimated, the proposal here is to change the paradigm of such analysis into a global analysis with several signal regions from different physics channels and explore performing systematic studies in one go, to reduce the overall uncertainty on precision measurements. Both ATLAS and CMS groups have experience on some specific channels, viz. the search for Flavour Changing Neutral Currents (FCNC) in CMS and, more recently, the study of the structure of the *Wtb* vertex at ATLAS. Expertise on the technical solutions to perform combined simultaneous fits to data from ATLAS and CMS is also available in the network, esp. in what concerns the Higgs sector. In order to achieve the ultimate precision, a strong effort needs to be done in this direction i.e., of reducing the possible contributions from systematic uncertainties and, one way to achieve that is to perform a global analysis. In terms of event selection, signals and observables are searched for in terms of a global event selection, which identifies different signal regions (for the different physics processes) according to:

1. Jet multiplicity information i.e., by counting the number of jets and knowing where they are, and separate the jets in the different acceptance regions according to the different signal regions and processes under study;
2. Lepton multiplicity: $n = 1$ and $n = 2$ for $tt+X$ $(X = \gamma, Z, W, H)$ and single top processes, $n = 3$ for FCNC decays, and $n > 3$ for multi-leptons and multi-messengers searches;
3. Missing energy and other variables;
4. Make sure the different signal regions are statistically independent (orthogonal).

Although this may look similar to a traditional analysis, the concept here is to perform a global analysis by organizing the physics processes themselves (top quark production, single top quark production, Higgs production, etc.) in a global single analysis. The steps are the following:

1. Perform a joint search of couplings of the *Wtb* vertex from ATLAS and FCNC from CMS in one go;
2. Extend the study of the couplings to the enlarged neutral sector by progressively including $tt+X$ production ($X = \gamma, Z, H$), including as well the search for 4 top-quark production and other Higgs bosons decays;
3. Construct experimental observables optimized to probe the Wilson coefficients and fit for all of them simultaneously.

Reconstructing the kinematics whenever necessary, implies the development of global fitters of data, looking for events with a given number of W, Z, and H bosons, and top quarks. Several observables are expected to be developed for the global fit to better constraint the SMEFT and test for BSM fingerprints. The mass and width of fundamental particles (top quark, Higgs boson, W and Z bosons, etc.) are expected to be reconstructed and used in the global fit as input parameters, together with the cross-section numbers calculated in the WP1, as well as the corresponding differential distributions. **The individual projects of ESRs in WP2** cover the measurements of:

- Mass;
- Angular distributions;
- Production cross sections;
- CP nature of couplings.

A global fitting code is expected to be delivered, i.e. a fitter that reconstructs and categorizes events according to the number of top quarks, W, Z and Higgs bosons, present in the events. A fitter to be applied for extracting the SM underlying parameters and Wilson coefficient values, is also expected to be delivered.

The WP3 "The LHCnet Machine Learning Program and Society Interface". In contrast to traditional neural networks, which often need manually-constructed input variables to achieve good discrimination, deep neural networks (DNN) have several layers and are able to learn non-linear relations which allow for improved separation between signal and background. The main objective of this work package is to **develop advanced tools based on Machine Learning techniques to efficiently categorize signal regions** of the global analysis, without the need of relying on rigid event selection criteria. **This tool is expected to be extended to the industrial applications.** In addition, a deep neural-network based reconstruction tool will be developed that will allow to better reconstruct top quark and Higgs boson decays in comparison to the currently used kinematic likelihood fitters. This will not only improve the resolution of the reconstructed mass and kinematic distributions, but also allows to define additional observables that will be sensitive to one or more Wilson coefficients. The focus will lie on current state-of-the art software such as Keras and Theano. Given the progress of the studies, Machine Learning techniques are expected to be developed for the global analysis. The event categorization may use Machine Learning based tools to separate and categorize the different types of signals. Applying fixed selection criteria may reduce the significance or precision of a potential measurement. The fact that there is an overwhelming amount of possible combinations of possible selections on object properties (transverse momentum, energy, mass, etc.) makes it quite natural to employ Machine Learning, Deep Learning, Neural Network, etc. based methods, where searches for patterns, are indeed more efficient. These tools, developed to identify patterns, will be extended to the ongoing Industry developments (described in the Industry interface of this network). **The individual project of ESRs in WP3**, long-term students, is associated to the development of ML tools, which can be bridged to the other projects of WP2 and the secondments to industry.

The WP4 "The LHCnet Hardware and Image Processing" main objective is to develop the design of next generation systems for Image Acquisition and Processing that could be used in the field of Biological Sciences or the industry. This WP is intimately connected with the software developments of WP3. The design of new, more efficient data acquisition systems that can acquire images at a speed that matches the production line requirements of several thousand pieces a day is of utmost importance for the industry, to control and limit financial losses that may be quite significant, as previously discussed in the case of Bosch. These devices to be developed, are expected to replace the ones currently in use. As has happened recently, the increasing number of defects identified by the systems already installed in the production lines, viz. the identification of circular defects, linear defects, etc, allows a systematic topological and mathematical approach to the problem, which indeed has been used, to identify the properties of each one of the different types of defects. This methodology has so far been used in the industry with great success. Nevertheless, given **the number of increasing different different types of defects and different products being monitored, the solution points towards the use of ML techniques to separate good from defective pieces in industry in industry**. **The individual project of ESRs in WP3**, the long-term students, is associated to the training on ML tools, developed in close connection to WP3, particularly useful for this type of application. Both hardware and software components of the system designed by the ESRs is expected to be a deliverable from the network.

The WP5 "Inter-project Activities" main objective is to facilitate close interaction between theory projects in WP1, and the experimental studies pursued in the several projects defined in WP2 from ATLAS and CMS (mass studies, cross sections measurements, angular distributions, CP violation studies). It is important that the overall work performed in WP2 closely follows the projects in WP1 and effective communication between those is mandatory for a sensible global analysis of data: it is important to understand how the different observables explored by the different projects in WP2 can be interpreted in the SMEFT framework in a consistent way. The development of tools to improve signal significance allowing to relax the selection criteria applied in the projects in WP2 will use new ML techniques in WP3. Those techniques need to be exercised back to the projects on WP2, in order to understand the improvements. As these projects are realized by distinct ESRs, inter-project activities are very beneficial for the network, ensuring that knowledge is transferred between ESRs associated to different projects. It is important to mention at this point that several tools developed by members of the network are already in use in applications in industry, which will be improved by the use of the ML techniques in WP4. Dedicated inter-project workshops, during network schools and network meetings, will be organized to make sure that inter-project knowledge transfer is achieved. In these activities, public sessions are foreseen to allow to spread the information to the wider society.

1.1.3 Originality and innovative aspects of the research programme

There are several innovative aspects in the LHCnet. These can be summarized as:

- The possibility of surveying the highest order calculations associated to the production cross sections of the different processes under study, i.e., top quark pair production, $tt+X$ ($X = \gamma, Z, W, H$) production at Next to Leading Order (NLO) with Next-to-Next Leading-Log (NNLL) resummation of soft gluons, **understanding the best observables sensitive to the underlying fundamental parameters of the SMEFT parametrization** (Wilson coefficients) and proposing new ones.

- The possibility of performing the **analysis of several signal regions from different physics processes (top quark pair production, single top quark production and Higgs production, in resolved and boosted phase spaces) simultaneously in a global analysis**, across two LHC experiments and research groups, is unique;
- The possibility of **performing a global fit of the underlying parameters of the theory to all the signal regions at once**, by choosing the appropriate theoretical dependencies, probing correlations among the parameters and search for deviations with respect to the SM.
- The **development of Machine Learning techniques to progressively assume the responsibility of categorizing globally the events into the different signal regions**, belonging to different physics processes, expected to take over after the first milestones have been achieved.
- The development of **Machine Learning techniques to fully reconstruct the top quarks and Higgs bosons in order to define the new observables**.
- **The Machine Learning techniques are expected to be extended as tools that can be used in concrete industrial on-going projects**, to categorize several properties of products in the production plants, in a similar way as used previously in the research programme for the global analysis; the interplay between institutions with expertise on hardware, data acquisition systems, ASIC design, image processing, and analysis is particularly relevant for the network and strengthening the exchange to the industry, detailed in **Section 1.2.2**.
- The interplay between science and society, with a clear sharing of expertise and experiences among senior researchers, ESRs, and high school students.

Table 1.2a: Recruitment Deliverables per Beneficiary

ESR Number	Recruiting Participant	PhD awarding entities	Planned Start	Duration (months)
1	UCPH	yes	M6	36
2	UCPH	yes	M6	36
3	UC	yes	M6	36
4	VUB	yes	M6	36
5	DESY	Hamburg U. (Legal Link)	M6	36
6	UMAN	yes	M6	36
7	UM	yes	M6	36
8	UCOM	yes	M6	36
9	ALU-FR	yes	M6	36
10	PU	yes	M6	36
11	UTBv	yes	M6	36
12-13: Short-term	UCPH	yes	M6-M38	9 total (est.), 4.5 months average
14-16: Short-term	UC	yes	M6-M38	15 total (est.), 5 months average
17-19: Short-term	VUB	yes	M6-M38	15 total (est.), 5 months average
20-22: Short-term	DESY	Hamburg U. (Legal Link)	M6-M38	15 total (est.), 5 months average
23-25: Short-term	UMAN	yes	M6-M38	15 total (est.), 5 months average
26-28: Short-term	UM	yes	M6-M38	15 total (est.), 5 months average
29-31: Short-term	UCOM	yes	M6-M38	15 total (est.), 5 months average
32-34: Short-term	ALU-FR	yes	M6-M38	15 total (est.), 5 months average
35-37: Short-term	PU	yes	M6-M38	15 total (est.), 5 months average
38-40: Short-term	UTBv	yes	M6-M38	15 total (est.), 5 months average
Total				**540**

1.2 Quality and innovative aspects of the training programme

1.2.1 Overview and content structure of the training (ETN)

An extensive training programme has been designed for the ESRs, allowing them to get a broader overview in particle physics in general, as well as providing them with skills and training that are essential also for a career outside of academia. **Each ESR will be paired with a mentor who will be advising the ESR in addition to the supervisor at his host institute.** This mentor will be chosen from one of the other institutes, ideally such that a student working on experimentally particle physics will have a theory expert as mentor, and vice-versa. **Two secondments are foreseen in the scope of the three years: one academic and a non-academic secondment.** The academic secondment will take place at one of the partner institutes or at CERN, where the ESRs will have the opportunity to work closely and build a network with other experts in their field.

Regular network meetings will take place which will be hosted at one of the host institutions. In these meetings, an overview over the different network activities will be given and the ESRs will have the opportunity to present and discuss their research projects. Moreover, Annual Schools are planned which will be also open to other students outside the ETN. In the Annual Schools, lectures and tutorials will be given in the area of experimental and theoretical particle physics as well as programming and machine-learning techniques.

1.2.2 Role of non-academic sector in the training programme

The role of the non-academic sector is crucial for the training programme of the ESRs and is **twofold.**

Firstly, to present the ESRs with a more detailed outlook on **possible future career choices**, we will invite speakers outside the field of particle physics, for example representatives from the financial sector, medical physics, or from tech companies such as Google, in the context of the Annual Schools and network meetings. All ESRs will take part in career training programmes, offered locally by the Beneficiaries and Partners, which will allow ESRs to further improve their presentation and management skills. In addition, ESRs can take part of the CERN Alumni programme, which organises networking events where CERN alumni that left the field are invited to talk about their career development, necessary skills for a career outside of physics, as well as provide help with applications such as writing the CV, prepare the transition outside of academia, etc.

Secondly, once many of the students already trained by the Beneficiaries and Partners have followed career paths outside academia either in the industry or in companies from the financial and insurance systems, it is important to offer students non-academic secondments plans. As mentioned in **Section 1.1.1,** a collaboration with Bosch (our main non-academic partner) comprising as well its affiliates worldwide, has been ongoing since 2016, under a established Cooperation Protocol (iSci-Bosch-ECUM). **Given the fact the protocol was negotiated with the main house of Bosch in Germany, it should be understood that the Collaborative Activities (CA) foreseen in the protocol, include not only Bosch but also their affiliates, wherever they are**, as specified in the contract signed for the CA(s). This model has been particularly successful in terms of students employment rates, around 85% (defined as the fraction of students involved in the CA that were hired by Bosch). The remaining students decided to follow a career path in the academia. The model followed for the CA involved Bosch providing the necessary resources to allow the acquisition of all equipments and devices necessary to assemble the systems designed for each CA, and the academia bringing the students and supervision know-how. The network intends to proceed according to these lines, **involving the ESRs in the CA, specifically helping to design and build new systems for the production lines** and using the machine learning techniques developed by the network. Given the diversity of problems offered by Bosch within the "Optical Bonding" CA, the training of the ESRs will allow them to develop a wide range of skills. The training of technical skills will involve:

1. The design of optical systems with hundred million pixels,
2. The development of the hardware associated to data readout and storage,
3. Software development for pattern recognition of the different properties of the manufactured products, and
4. Installation of the full system in the production plants.

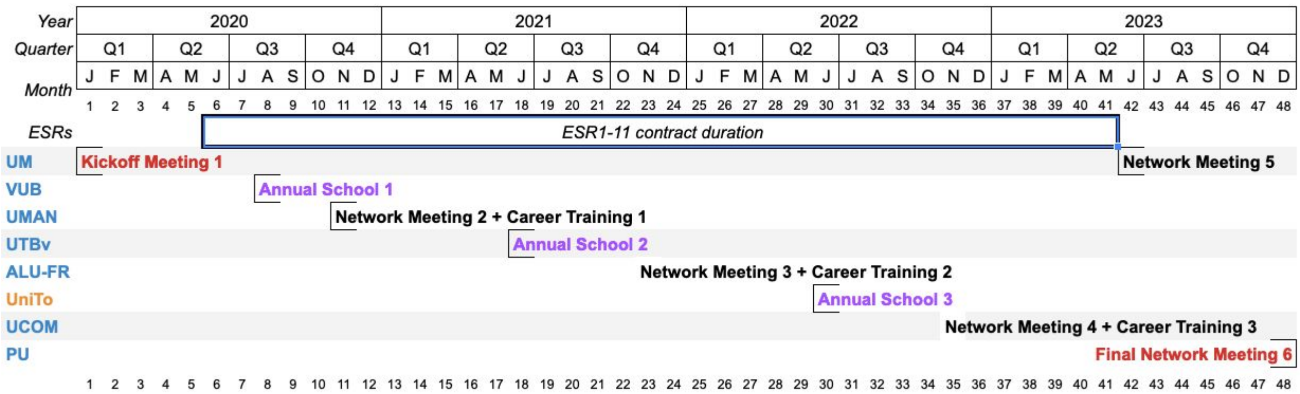
The training of the soft and transferable skills is improved through

1. The regular presentations of the results obtained so far in the production plant and
2. Overall management of their impact in the full production chain.

Table 1.2b: Main Network-Wide Training Events, Conferences, and Contribution of Beneficiaries

	Main Training Events & Conferences	ECTS *(if any)*	Lead Institution	Action Month (*estimated*)
1	Network kickoff meeting 1		UM	M1
2	Annual school 1		VUB	M8
3	Network meeting 2		UMAN	M11
4	Career training 1		UMAN	M11
5	Annual school 2		UTBv	M18
6	Network meeting 3		ALU-FR	M23
7	Career training 2		ALU-FR	M23
8	Annual school 3		UniTo	M30
9	Network meeting 4		UCOM	M35
10	Career training 3		UCOM	M35
11	Network meeting 5		UM	M42
12	Final network meeting 6		PU	M48

Schedule of Main Network-Wide Training Events, cf. Table 1.2b above.



The ESRs will therefore be provided with close contact with a highly competitive non-academic sector, which monitors continuously the efficiency of solutions, their timely development, and improvements on loss rates. **From 2016 to 2018, Bosch hired 11 students** (the same number of ESRs proposed to hire in this network) for 6 months each and provided a significant amount of resources for the ongoing CA. **Bosch is interested in and willing to develop new Collaboration Agreements (CAs)**. Given the fact that these CAs depend on individual contracts between each Beneficiary and Bosch, the precise nature of the secondment will be negotiated on a project-by-project basis between parties, as was done for the "Optical Bonding" CA. Bosch has its own training programs where soft skills related to communication in the industrial world, effectiveness and goal oriented performances, and new ways of thinking, can be developed. During the secondment foreseen in the individual projects (**Table 3.1d**), Beneficiaries associated to secondments will have their team leaders monitoring all aspects of the secondment and the training received by the ESRs. As requested by the contracts signed by both parties for the differents CAs, the actions to be carried out under the existing Protocol:

- Clear identification of activities;
- Identification of Bosch and Beneficiary supervisors;
- Clear workplan;
- Supervision of the activity; and
- Evaluation process.

1.3 Quality of the supervision

The institutions involved in the LHCnet are among the best institutions providing training and supervision in the field of HEP (both theory and experiment), with leading laboratories like CERN and DESY, and can provide extremely high quality training programmes. In recent years these programmes have allowed testing the SM to an unprecedented precision and allowed the discovery of new particles, like the Higgs boson in 2012, by both ATLAS and CMS, at CERN. Although the LHCnet focuses on new ideas for techniques and tools to be developed within the network programme, this comes in addition to the already existing training programmes of the Beneficiaries and Partners of the network. These also cover a wide range of extremely high level academic and non-academic training programmes in HEP that the ESRs will profit from, including lectures, seminars, and workshops. Both Long-Term ESRs and Short-term ESRs will have access to the same local facilities and training opportunities, offered by the Beneficiaries and Partners. All members of the network will be encouraged to travel within the network for short secondments among projects and groups. The network meetings, schools, and career training events are particularly useful for this multi-experience exchange. The connection with non-academic partners and industry will expose the ESRs to a different type of training on well-defined projects under CA agreements, in a competitive environment that our partners are particularly fond of. The LHCnet also allows the ESRs to profit from the interaction with other PhD students and Postdocs from the Beneficiaries and Partners, exposing them to new cultures and ways of thinking. The Short-term students will spend part (around 10%) of their full PhD training programme exposed to the LHCnet training programme, which adds an enormous value to their own PhD. The Supervisory Board of the network will carefully monitor the quality of the their training programme. They will also be able to profit from the non-academic sector training foreseen in the network. One particularly important aspect of the network is to obtain feedback from the students, which will be continuously monitored by the Supervisory Board. The LHCnet takes very seriously this feedback and will give the opportunity to the ESRs to organize their own training events, through a decision-making process within the Students Research Assembly. ESR representatives will be able to provide insight to the network through the Supervisory Board. It should be noticed that the overall workload in supervising the ESRs (Long-term and Short-term) among the members of the network corresponds to approximately one per core academic member, which is less than their available supervision capacity.

1.3.1 Qualifications and supervision experience of supervisors

All the supervisors of the Long-term ESRs (**Table 1.2a**) are clearly identified in **Table 3.1d** under the topic **"Enrolment in Doctoral degree(s)"**, as well as the institution responsible to provide the PhD degree. **Section 5** provides additional information on supervisors. All have extensive qualifications and experience in research, teaching, supervision, and management. They have published more the 3,500 papers in peer reviewed journals, acted as coordinators and Heads of several research laboratories and Physics Departments, chaired several Committees within LHC experiments and the European Commission, earned teaching prizes, and supervised a significant number of undergraduate, graduate, MSc, and PhD students, and Postdocs. The quality of their supervision is backed up by their home institutions, which have the legal responsibility of issuing the PhD degree. For joint supervisions, the involved Beneficiaries have already well defined procedures to ensure the quality and monitoring of the students when performing their work outside their home institution. The Short-term supervisors are clearly identified among the academic members of the Project Management Board, when the openings for the studentships are available and publicised. As the period of time the short-term students spend within the network, is a small part of their total PhD programme (around 10%), the work plan for the the short-term students must be agreed between the LHCnet supervisor and their home institute supervisor. The quality of the training of the short-term students is monitored by the Project Management Board. The feedback from the short-term students is quite important for the LHCnet, since they may provide valuable information concerning different experiences, PhD programmes and methodologies. This is accomplished through the Students Research Assembly, which provides feedback to the Project Management Board.

1.4 Quality of the proposed interaction between the participating organisations

1.4.1 Contribution of all participating organisations to the research and training programme

All beneficiaries and partner organisations will actively participate in the research project proposed above. The long-term ESR are distributed evenly between all experimental beneficiaries, while a more flexible approach is planned for the short-term ESRs. We identified synergies between the different projects, which are pointed out in **Section 5**. Each long-term ESR will have, in addition to his local supervisor, a mentor from a different institute. This will allow for further collaboration and additional support of the ESR. The beneficiaries and partner organisations will all contribute to the design and execution of the training programme in the different aspect of the programme (supervision, secondments, annual schools, etc).

1.4.2 Synergies between participating organisations

All beneficiaries and ESRs will participate in several of the work-packages defined above. For the experimental projects defined, many ESRs rely on the usage of similar tools that will be shared and further developed amongst the different projects. The development of an improved event reconstruction tool is hugely beneficial for the majority of the analyses planned and will be done with the support of various ESRs.

Additional tools that are needed by several of the measurements planned (e.g., unfolding code) will be developed and shared amongst the ESRs, to avoid duplication of work and will allow the different measurements to move forward faster. The training programme proposed in the network meetings and annual schools will bundle the resources in order to provide a good fundamental training for all ESR and allow to provide an educational programme that would not be possible to provide at the individual institutes alone. This goes beyond the network itself, since also students outside the network will be able to participate in the lectures and tutorials at the annual schools.

1.4.3 Exposure of recruited researchers to different (research) environments, and the complementarity thereof

It is highly beneficial for the ESRs to experience different learning and working environments during their PhD project. Firstly, a secondment of an ESR working on experimental particle physics in a theoretical particle physics group (and vice-versa) provides valuable insight in the different approaches for problem solving and enables the ESR to acquire additional knowledge and skills. The regular exchange with their collaborators at the different institutes will further help them to broaden their view on their own research and reflect and adapt their own work. The crucial part of the training programme is the non-academic secondment, where the application of the ESRs skills to real-life problems will be an experience that will allow the ESR to approach problems with a more hands-on approach and expose them to an environment very different from the academic sector.

2. Impact

The goal for long- and short-term ESR is to provide them with a training and a set of additional skills, that make them attractive candidates for positions in and outside of academia.

2.1 Enhancing the career perspectives and employability of researchers and contribution to their skills development

For the long-term ESRs who will be part of the training network for 36 months, we foresee a comprehensive training program as described above. The students will learn how to develop and manage projects, distribute work among their collaborators, and how to successfully approach and solve problems. During their training, all of them will develop, test, and document computer code, and acquire additional programming skills. In our research field, cluster computing is of the utmost importance. The students will have access to the worldwide LHC computing grid (WLCG) as well as large computing farms available at the individual participating organisations. Another fundamental part of their training will be the learning of statistical methods that they will be using for the analysis and interpretation of their obtained results. These skills will be very valuable outside of academia, for example for data scientists, in the financial sector, or the insurance business.

For a successful career of the students, management skills are of the utmost importance. The students will help with the organisation of the annual network meetings and the annual schools, including the definition of the meeting agendas and will chair their own student sessions. With respect to communication and dissemination of their results, the LHCnet emphasises two key aspects:

- That ESRs present their own research results to their peers during the network meetings and at international conferences, and
- That ESRs take part in outreach events and visits to high-schools, where they will explain particle physics to a non-expert audience.

This will not only greatly improve the communication skills of ESRs on the professional level, but also teach ESRs how to explain complex topics on a more simplified level. In addition to improving their english language skills, they will work and exchange ideas with people from different scientific and cultural backgrounds.

The academic secondment will allow the students to work on additional projects and extend their research portfolios. This will allow them to create a larger network and increase their visibility in the field. Being part of the ETN will enable the students to travel and work with different experts, which is vital for the work in the particle physics community.

A central part of the training programme is the non-academic secondment, that all long-term experimental ESRs can participate in. Having the opportunity to work in a company and employ and broaden their skills in an industrial environment is unique and will make them stand out when applying for positions after graduation. They will learn and employ state-of-the-art machine learning techniques which are increasingly used in all kind of sectors. In addition, they will have already the connection to the industrial partner, who would also benefit from having this connection with potential future employees.

The short term students will also hugely benefit from the training they will receive from the training network. They will be able to contribute to projects which are different from their own PhD topic and may lead to additional publications. Therefore they will be able not only to extend their research portfolios but also to build a network in the particle physics community. Furthermore it will allow them to travel and spend time at another institute and different research environments. In addition, they can take part in the annual schools where the lectures and tutorials will add to their training and extend their skill sets.

Since the annual schools will be open to students who are not performing a dedicated project in the ETN, the training provided will also add a value to the particle physics community as a whole. Good programming skills, the knowledge of machine-learning techniques, and a solid education in statistical methods are of fundamental importance for all ESRs and a big asset for any future project. All skills discussed are imperative for their future careers and will hugely increase their employability for the non-academic sector as well.

2.2 Contribution to structuring doctoral/early-stage research training at the European level and to strengthening European innovation capacity

2.2.1 Meaningful contribution of the non-academic sector to the training

The impact of the doctoral/early-stage research training will go far beyond LHCnet itself. While the focus of the research program lies on theoretical and experimental particle physics, the training program aims for a broad education of the ESRs, one that will allow them also to follow a successful career outside of academia and employ their skill sets in industry, the financial sector, or in other tech companies.

The long-term ESRs who will perform a secondment at Bosch will learn there how to apply their know-how in a more commercial environment and in return gain insight into a different work environment. In order to allow more ESRs to have this experience, we will invite representatives from Bosch to the annual schools, such that also students outside the network will be informed about possible future career choices. This will not be limited to our partner organisation Bosch, but we will also invite speakers from other companies outside of particle physics to talk about job opportunities for high-skilled particle physicists. For this, we will also contact former particle physicists, who have a better insight in the transition between academia and industry and give useful advice for the ESRs.

This information will also be useful for PhD candidates who want to stay in academia after obtaining their degree. Their day-to-day work is based on finding ways to approach and solve problems, and using new methods and software tools. Especially in the realm of machine-learning techniques, the developments are being made at enormous pace and to ensure the training of the students on the latest industry standard is highly desirable. All our training structures aim to increase the mobility and flexibility of the ESRs and increase their research portfolio in order to increase their employability in Europe, both in and outside academia.

2.3 Quality of the proposed measures to exploit and disseminate the results

2.3.1 Dissemination of the research results

All results obtained in the ETN will be submitted to peer-reviewed journals. When submitting the papers to the journal, the results are at the same time made available to the public (Open Access). This is done using the pre-print server arxiv.org. For measurements of differential cross-sections, the results are furthermore made available using HepData, a platform where the main physics result together with a detailed breakdown of the systematic uncertainties and the migration matrices are stored and can be used for further interpretation. In order to allow future comparison of the unfolded spectra with new MC generator predictions, the measurements are furthermore stored as so-called Rivet-Routines, which contain an implementation of the event selection used, the object definition and the kinematic distributions, including the data distribution for all observables. Additional work is necessary to implement DNN selections within the Rivet framework. Rivet routines are valuable input for any future MC generator study. For important findings of our research, the individual institutes will prepare press releases in order to inform the general audience. All ESRs will regularly present their findings at network meetings and annual schools as well as national and international conferences. Another forum to disseminate our research within the particle physics community are the workshops and regular meetings organised by the LHC Top Working Group and LHC Higgs Cross-Section Working Group, where experts from experimental and theoretical particle physics discuss about the latest results in their respective areas. The lectures and tutorials presented in the annual schools will also be made public, to reach a larger target audience and allow for more students to benefit from the program. All members of the network will be proactive in publicising the main achievements and results of LHCnet throughout the main international schools, Workshops and Conferences.

2.3.2 Exploitation of results and intellectual property

The deliverables, in the form of software packages, will be distributed worldwide through dedicated web pages with supported repositories (like for instance HepForge) or wiki pages, commonly used by the LHC experiments and the theoretical community. The network software tools and packages will be distributed under Open Source licenses, for use in the academic framework. A repository link and a digital object identifier (DOI) for each publication will be provided in the project reports. Intellectual Property questions will be dealt within the DESCA Simplified Consortium Agreement, where a member of the consortium has the possibility of protecting its own legitimate work. Specific issues related to the non-academic secondments will be negotiated with the Partners, including the necessary reporting back to the network of the achievements obtained by the ESRs, at the start of the network. Clear agreements, in the form of contracts, similar to what was done for the “Optical Bonding” CA, will be in place between Beneficiaries and Partners for non-academic secondments.

2.4 Quality of the proposed measures to communicate the activities to different target audiences

2.4.1 Communication and public engagement strategy

The members of this ETN have extensive experience in communicating our research to different target audiences. This has been done either locally at the respective home institutes, in local schools or at science fairs, but also to wider audiences such as performing guided tours at CERN or taking it to an international level for example by taking part in the international Masterclasses program (see below). The proposed projects do not only include the dissemination of our work and results to the general public, but also to provide additional support to interested high-school teachers. The latter is of special value, since teachers will act as multiplicators and can encourage their students to think about a higher education in science. Several actions are planned as described in the following:

- **CERN Visitor centre** During their secondment at CERN, the ESR will be trained as tour guides, including a communication course. Tours are mainly given in English, German, and French (but not only), and there is usually a very high demand for tour guides. This is a good opportunity to inform the public about the work done at CERN and to answer their questions, which is always a very inspiring experience.
- **International Masterclasses** All beneficiaries are regularly taking part in the international “Hands-on particle-physics” masterclasses program, where high-school students can get a first introduction to particle physics, analyse real collision data and discuss their findings with other international institutions in a video conference.
- **CERN teachers programmes** CERN has a national teachers programme, where teachers from all over the world come to CERN to improve their knowledge about particle physics. This is a very important programme, since good and motivated teachers will act as a multiplicator and encourage also their students to develop and interest in physics. The ESR will be encouraged to part in this effort in order to improve the connection between schools and research.
- **Teaching the next generation** In Germany, the “Netzwerk Teilchenwelt” (https://www.teilchenwelt.de/) is a successful institution which provides material and training to particle physicists in order to perform outreach projects and supports the training of teachers for modern particle physics. In the scope of this network, we will encourage the ESRs based to work with high-school students either directly in their schools or doing little projects with them at the university. Recent successful events are the “International cosmic day” and two-week research projects of students at CERN. Some of the beneficiaries in Germany are already part of this network.
- **"LHCnet ROCKS - LHCnet Reach Out, Connecting Knowledge and Scientists"** introduced in Section

1.1.1. The development of this programme is an integral part of the network activities, with a public session planned in each of the proposed six network events.
- **Public lectures "Science to go!"** for students and general public, organized regularly by a dedicated and broader Czech team, and co-hosted also by the Research Library in Olomouc 3 times yearly.

3. Quality and Efficiency of the Implementation

The LHCnet training and research network proposed here, will be implemented by the following Beneficiaries: University of Minho (UM), University of Manchester (UMAN), Vrije Universiteit Brussel (VUB), Transilvania University of Brasov (UTBv), University of Freiburg (ALU-FR), Palacky University (PU), University of Copenhagen (UCPH), Deutsches Elektronen-Synchrotron (DESY), University of Coimbra (UC), and Comenius University (UCOM). The partners organizations associated to the proposal are: Bosch, University Autonoma de Madrid (UAM), University of Torino (UniTO), University of Heidelberg (UHeid), and CERN.

The network members have many years of experience in the research and training areas of the proposed programme of the network, being either associated as conveners of ATLAS and CMS research groups and sub-groups (top quark and Higgs boson), or being responsible for the latest developments from the theory side on the SMEFT framework, or even being experts on detector development and related instrumentation. All this expertise is performed within the LHC community, fulfilling the highest standards of quality and efficiency. The network proposed is able to deliver the training and research expressed in the network programme at an extremely high level.

3.1 Coherence and effectiveness of the work plan

As discussed throughout this document, all the activities performed by the network are organized in work packages (WP) which allow to clearly identify the overall workload expected to be realized by the LHCnet network. Each one of the proposed work packages has clear connections to the individual projects of the ESRs, with clear deliverables and milestones. While some of the WPs are necessarily related to training and research (WP1-5), others are dedicated to networking and dissemination (WP6-11) and management WP12), and particularly useful for the co-ordination of the ESR projects.

3.1.1 Work Packages description

In **Section 1.1.2** the details of the several WPs proposed are discussed. Here, a summary of all WPs, their objectives and deliverables are presented. Since a thorough description was performed in **Section 1.1.2**, we refer to that section for further details on the work packages. In the following, the different WPs are summarized, including their inter-relations and connection to ESR projects.

Table 3.1a: Description of Work Packages

WP Number	1	**Start Month-End Month:** 1 - 48
WP Title	Theory in a Nutshell Approach	
Lead Beneficiary	UCPH	
Objectives Review the status of the SM, in what concerns the level of precision of measurements (cross sections, differential distributions, angular distributions, etc.) and develop the SMEFT framework for the global fit of data.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations The WP1 is divided into two parts the first one concerns revisiting the actual status of the SM theory and check the contributions of higher order corrections for top and Higgs production at the LHC. Identify all the relevant operators of SMEFT that can be probed within the multi-messengers physics signals studied at the LHCnet and select the ones most appropriate for the global fit. This WP will be lead by **Michael Trott** from UCPH (see Section 1.1.2 for further details).		
Description of Deliverables: Develop the SMEFT framework and provide the list of most relevant operators that should be probed and observables used in the global fit of SMEFT.		

WP Number	2	**Start Month-End Month:** 1 - 48
WP Title	The LHCnet Global Analysis	
Lead Beneficiary	UM/UMAN	
Objectives The main objective of this work package is to perform a global analysis of data from different signal regions and different experiments across the LHC.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations Precision measurements require new data analysis strategies for the LHC. In this package, precision measurement of particle masses, particle properties, cross sections and measurements on the CP nature of the couplings are performed, in ATLAS and CMS in order to get the ultimate precision on the SMEFT parameters using a global analysis of ATLAS and CMS. This WP will be lead by **A.Onofre** from UM and **Reinhild Peters** from UMAN (see Section 1.1.2 for further details).		
Description of Deliverables: A global fitter is expected to be delivered i.e., a global fitter that reconstructs and categorizes events according to the number of top quarks, W, Z and Higgs bosons present in the events. A fitter to be applied for extracting the SMEFT underlying parameters and Wilson coefficients is also expected to be delivered.		

WP Number	3	**Start Month-End Month:** 1 - 48
WP Title	The LHCnet Machine Learning Program and Society Interface	
Lead Beneficiary	ALU-FR	
Objectives The main objective of this work package is to perform the development of highly skilled tools based on Machine Learning techniques to efficiently categorize signal regions of the global analysis.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations Machine Learning techniques are expected to be developed for the global analysis. The event categorization may use Machine Learning based tools to separate and categorize the different types of signals. The fact rigid cuts are applied, completely blind to each other, may reduce the significance or precision of a potential measurement. The ML tools will be extended to the ongoing industry developments (described in the Industry interface of this network). ML techniques will also be employed to improve the reconstruction of the top quark and the Higgs boson. This WP will be lead by **Andrea Knue** from ALU-FR (see Section 1.1.2 for further details).		
Description of Deliverables: A Machine Learning package that allows categorizing and reconstruction of the events according to the underlying physics process. This tool is expected to be extended to the applications of the industry with the possibility of categorization different types of defects or image characteristic properties.		

WP Number	4	**Start Month-End Month:** 1 - 48
WP Title	The LHCnet Hardware and Image Processing	
Lead Beneficiary	UTBv	
Objectives The main objective of this work package is to develop the design of next generation systems for Image Acquisition and Processing that could be used in the field of Biological Sciences or the industry. This WP is intimately connected with WP3.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations Design of new, more efficient data acquisition systems that can acquire images at a speed that matches the production line requirements (several thousand pieces a day). This WP will be led by **Mihai Ivanovici** from UTBv (see Section 1.1.2 for further details).		
Description of Deliverables: A full working system (hardware+software) that could be used to identify, reconstruct and treat images that can be used by the industry or medical sciences entreprises.		

WP Number	5	**Start Month-End Month:** 1 - 48
WP Title	Inter-Project Activities	
Lead Beneficiary	DESY	
Objectives The main objective of this work package is to develop common studies between the members of the LHCnet network to make sure there is concrete knowledge transfer among the different analysis, interpretations, tools and systems developed, among the members.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations The work foreseen for this work package relates to the observables studied in WP2 and their interpretation within the SMEFT framework in WP1 performed jointly between projects, the tools used in WP3 and their transfer to the wide society WP4, as well as the common outreach and dissemination activities. **Andreas Meyer** from DESY will be responsible for this WP (see Section 1.1.2 for further details).		
Description of Deliverables: Commons studies, interpretations and tools for data analysis and global fits + online tutorials for wide spread of the information and discussion throughout the network.		

WP Number	6	**Start Month-End Month:** 1 - 48
WP Title	Long-term ESR training	
Lead Beneficiary	VUB	
Objectives The main objective of this work package is to ensure the high quality of the long-tem ESRs (doing a full PhD) in the network.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations The long-term ESR will start the full PhD training, through formal courses and training following the local available programmes. This WP covers the recruitment, initial training and network monitoring of the long-term studentship programme and will be coordinated by **Jorgen D´Hondt** from VUB will be responsible for this WP (see Section 1.1.2 for further details).		
Description of Deliverables: 11 PhDs in High Energy Physics, both from theory and experiment.		

WP Number	7	**Start Month-End Month:** 1 - 48
WP Title	Short-term Studentships	
Lead Beneficiary	UCPH	
Objectives The main objective of this work package is to ensure the high quality of the short-term ESRs in the network.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations The short-term studentships training programme will be coordinate by **Michael Trott** from UCPH which the typical activities associated to the publicity, selection, network monitoring and keeping in contact with ex-students. The local team leaders will be responsible for the appointment and supervision of the students in their own groups (see Section 1.1.2 for further details).		
Description of Deliverables: 144 of ESR-months of short-term studentships (approx. 30)		

WP Number	8	**Start Month-End Month:** 1 - 48
WP Title	Network Meetings	
Lead Beneficiary	PU	
Objectives The main objective of this work package is to organize one network meeting per year, in addition to the network kickoff and final meetings. At the end of the network meeting, Career training activities are foreseen.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations The organization of one network meeting each year, with a public session for the wider society, is planned in the current proposal. Six network meetings (including the kick-off meeting and final network meeting) are organised by UM (kickoff meeting), UMAN, ALU-FR, UHeid, UM and PU (final meeting). At the end of network meetings, Career Training workshops are foreseen, taking profit from the local partners own activities, to make sure soft skills are part of the training programme of the ESRs. **Jiri Kvita** from PU will coordinate this package (see Section 1.1.2 for further details).		
Description of Deliverables: 6 network meetings		

WP Number	9	**Start Month-End Month:** 1 - 48
WP Title	Outreach activities	
Lead Beneficiary	ALU-FR	
Objectives Ensure the ESRs training includes outreach programmes and all of them can contribute to the overall outreach programme of the network.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations The coordination of the outreach activities will be done by **Andrea Knue** from ALU-FR (see Section 1.1.2 for further details).		
Description of Deliverables: Several activities, within each one of the network meetings as well as dedicated activities through video-conference.		

WP Number	10	**Start Month-End Month:** 1 - 48
WP Title	Non-academic secondments	
Lead Beneficiary	UMAN	
Objectives Allocate non-academic secondments.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations The coordination of the non-academic secondment activities for the long-term ESRs will be done by **Reinhild Peters** from UMAN (see Section 1.1.2 for further details).		
Description of Deliverables: Non-academic secondments.		

WP Number	11	**Start Month-End Month:** 1 - 48
WP Title	Annual Schools	
Lead Beneficiary	UCOM	
Objectives Ensure the training quality of the network through Annual Schools		
Description of Work and Role of Specific Beneficiaries / Partner Organisations The continuity of the training programme year to year will be assured by several Annual Schools where the ESRs will be trained through all the aspects related to the programme of the network, including new results that might be found interesting for the students. At the end of each school, a public session will be organized for the wider audience. This work package will be coordinate by **Stano Tokar** from UCOM. The three schools envisaged in the network will be organized by VUB, UTBv and UniTO (see Section 1.1.2 for further details).		
Description of Deliverables: 3 annual schools.		

WP Number	12	**Start Month-End Month:** 1 - 48
WP Title	Network management	
Lead Beneficiary	UM	
Objectives Ensure the smooth running of the network.		
Description of Work and Role of Specific Beneficiaries / Partner Organisations Antonio Onofre will be responsible for all managerial and administrative activities not explicitly related to particular work packages, including financial monitoring, organisation of management meetings and delivering of reports to the REA.		
Description of Deliverables: Periodic, Progress and Final Reports		

3.1.2 List of major deliverables

The major deliverables are specified in Table 3.1b.

Table 3.1b. Major deliverables

Nr.	Deliverable Title	WP No.	Lead Beneficiary	Type	Dissem. Level	Due Date
Scientific Deliverables						
D1	Development of SMEFT framework, set of suitable operators to use in fit	1	UCPH	PDE	PU	M48
D2	Global fitting tool to extract Wilson coefficients	2	UM/UMAN	PDE	PU	M48
D3	Machine-learning software for event categorization and reconstruction	3	ALU-FR	PDE	PU	M24
D4	Full system to reconstruct images for industrial and medical applications	4	UTBv	PDE	PU	M48
D5	Online tutorials, common studies and interpretations, publication of Rivet analyses for differential measurements	5	DESY	PDE	PU	M1-M48
Management, Training, Recruitment and Dissemination Deliverables						
Nr.	**Deliverable Title**	**WP No.**	**Lead Beneficiary**	**Type**	**Dissem. Level**	**Due Date**
D6.1	Recruitment long-term ESRs	6	VUB	ADM	PU	M6
D6.2	11 PhDs in theoretical and experimental particle physics	6	VUB	R	PU	M48
D7.1	Recruitment of short-term ESRs	7	UCPH	ADM	PU	M24
D7.2	Short reports from short-term studentships	7	UCPH	R	PU	M32
D8	6 Network meetings	8	PU	OTHER	PU	M1 - M48
D9	Outreach events, within each network meeting	9	ALU-FR	PDE	PU	M1 - M48
D10	Non-academic secondments	10	UMAN	ADM	PU	M6 - M32
D11	Network schools	11	UCOM	OTHER	PU	M6 - M30
D12	Regular reports and final report	12	UM	ADM	PU	M48

3.1.3 List of major milestones

The major milestones are specified in Table 3.1c.

Table 3.1c. Major milestones

Nr.	Title	WP	Lead Beneficiary	Due Date	Means of Verification
M1	Recruitment of long-term ESR	6	VUB	M6	Report to PMB (Section 3.2.1)
M2	Recruitment of short-term ESR	7	UCPH	M24	Regular reports to PMB, short reports by ESR
M3, M4, M5	LHCnet Annual Schools	11	UCOM	M8, M18, M30	Annual report to PMB, including evaluation by participants

3.1.4 Fellow's individual projects, including secondment plan

The individual projects of the hired ESRs were already mentioned in Section 1.1.2. Here, the description includes the research goals, the expected results, and the identification of the WP packages, the projects are related to. A Gantt chart, in **Section 4**, provides a synoptic overview.

Table 3.1d. Individual Research Projects

Fellow	Host instit.	PhD enrolm.	Start date	Duration	Deliverables
ESR 1	**UCPH**	**Y**	**M6**	**36 months**	**D1,5,6.2,8,9,11**
Project Title and Work Package(s) to which it is related: "Theoretical developments in the Standard Model Effective Field Theory" (related to WP 1,5,6,7,8,9,11)					
Objectives: Formal developments of the Standard Model Effective Field Theory to sub-leading order.					
Expected Results: Consistent calculations in the SMEFT are possible beyond leading order in the perturbative expansion and non-perturbative expansion. Such results can introduce significant changes in the interpretation of experimental data. Developing such calculations is an ongoing enterprise in the theoretical community, but many formal issues remain to be resolved as many of the standard problems of Quantum Field Theories have a new challenge when considering this EFT extension of the SM. A few issues of note to be resolved are matching to sub-leading order using universal covariant one-loop actions and the interplay of sub-leading power corrections to this formalism. The calculation to sub-leading perturbative order also benefits from the recent development of the SMEFT with a novel gauge fixing approach, but the direct application of this approach to develop one-loop results, including one loop electroweak corrections is not in place as yet. This research project will devote itself to this goal with the minimal output of forming a more precise understanding of theoretical errors in interpreting the data in the SMEFT when restricting to a leading order analysis. The more ambitious output can be the systematic development of the SMEFT to sub-leading order in the non-perturbative and perturbative expansion, and even the examination of cross terms in this expansion and a precise conclusion as to how interpreting experimental results is modified when these corrections are included.					
Planned secondment(s): 6 months to UNITO for training in effective field theory at subleading order with G. Passarino; 2 months to CERN for experimental analysis understanding supervised by A. David. A non-academic secondment is available to the student, additionally.					
Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through University of Copenhagen, **under the supervision of M. Trott**.					

Fellow	Host instit.	PhD enrolm.	Start date	Duration	Deliverables
ESR 2	**UCPH**	**Y**	**M6**	**36 months**	**D1,5,6.2,8,9,11**
Project Title and Work Package(s) to which it is related: "Tool development in the Standard Model Effective Field Theory" (related to WP 1,5,6,7,8,9,11)					
Objectives: Development of software tools to interpret data in the context of SMEFT framework.					
Expected Results: Utilizing the results of the formal theoretical developments is challenging for the experimental community. This is due to the need to have usable tools for event generation to study the data in the SMEFT context. To this end the members of the proposal have been developing a leading order code package - the SMEFTsim package. This package needs to be extended with a number of results. The inclusion of input parameter redefinitions for flavour-changing effects is currently not incorporated and needs to be added. The usability of the results of SMEFTsim when considering global Higgs decay properties can be improved by developing specific codes that incorporate some of the results of SMEFTsim as an input. Chief among these results are dedicated code packages to calculate the top quark and Higgs decay total and partial decay widths. Further developments of these codes include the incorporation of the SMEFT gauge fixing procedure into SMEFTsim, and, more ambitiously, the development of one-loop QCD and then electroweak corrections into this simulation suite.					
Planned secondment(s): 6 months to UHeid for training and collaboration on the development of SMEFTsim beyond leading order in this manner with I. Brivio; 2 months to CERN for experimental analysis understanding supervised by A. David. A non-academic secondment is available to the student, additionally.					
Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through University of Copenhagen, **under the supervision of M. Trott**.					

Fellow	Host instit.	PhD enrolm.	Start date	Duration	Deliverable
ESR 3	**University of Coimbra**	**Y**	**M6**	**36 months**	**D1,5,6.2,8,9,11**
Project Title and Work Package(s) to which it is related: "Study of new observables and contributions of dimension six operators within the context of SMEFT for Higgs boson and top quark production at the LHC" (related to WP 1,5,6,7,8,9,11)					
Objectives: Study the impact of dimension six operators in the production of Higgs bosons and top quarks at the LHC, in several decay channels, and explored new observables, associated to angular angular distributions and asymmetries, most sensitive to BSM.					
Expected Results: Explore, from the theory side, new observables (angular distributions and asymmetries) in Higgs and top quark physics, to be used in the SMEFT global fit that can, at the same time, be sensitive to BSM.					
Planned secondment(s): 6 Months to Madrid, supervised by J.-A., Aguilar-Saavedra, in the second year, participation in the global fit of analysis and results discussion. A non-academic secondment is available to the student, additionally.					
Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through University of Coimbra, **under the supervision of O. Oliveira**.					

Fellow	Host instit.	PhD enrolm.	Start date	Duration	Deliverables
ESR 4	**Vrije Universiteit Brussel**	**Y**	**M6**	**36 months**	**D2,5,6.2,8,9,11**

Project Title and Work Package(s) to which it is related:
"Interpreting top-W/Z/H/g-quark interactions", (related to WP 2,5,6,7,8,9,11)

Objectives: The main objective of this project/dissertation is to use a combined analysis that takes already the expertise acquired during the simultaneous fit of ttbar and single top events (produced through the t-channel), used in the search of FCNC processes associated with top quarks and extend this to the interpretation of top-W/Z/H/g-quark interactions. Several multilepton final states (up to 3 leptons) and different flavors (electrons and muons) will be studied in a combined way, considering the different processes under study.

Expected Results: Global analysis interpretation of top-W/Z/H/g-quark interactions

Planned secondment(s): Academic secondment: 6 months at CERN, supervised by J.D'Hondt, in the second year, for participation in the global fit of analysis and strategy discussion. A non-academic secondment is available to the student, additionally.

Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through VUB University, **under the supervision of J. D'Hondt**.

Fellow	Host instit.	PhD enrolm.	Start date	Duration	Deliverables
ESR 5	**DESY**	**Y**	**M6**	**36 months**	**D1,2,3,5,6.2,8,9,11**

Project Title and Work Package(s) to which it is related: "Simultaneous measurement of differential production cross sections for top quarks in association with a heavy boson (H,Z,W)" (related to WP 1,2,3,5,6,7,8,9,11)

Objectives: The targeted signal processes have comparable production rates and similar final states, and are thus mutual backgrounds to one another. The objective is to perform a first simultaneous measurement of the differential cross sections and their correlations as input to the global fit. The results will be obtained by combination of unfolding and machine-learning techniques.

Expected Results: Demonstration and proof-of-concept differential measurement using the full Run-2 and possibly initial Run-3 data (recorded as of 2021). Use and development of a machine-learning-based tool for the unfolding of differential cross sections.

Planned secondment(s):
1) CERN, supervised by A.Meyer, in the second year (4 months) to refine the experimental analysis, and coordinate with other analyses, towards the global EFT fit;
2) UHeid, supervised by I.Brivio, in the third year (3 months) to perform EFT fit and interpretation.
3) A non-academic secondment is available to the student, additionally.

Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through Hamburg University, **under the supervision of A. Meyer (DESY) and E. Gallo (Hamburg U./DESY)**

Entity with a capital or legal link: University of Hamburg.

Fellow	Host instit.	PhD enr.	Start date	Duration	Deliv.
ESR 6	**University of Manchester**	**Y**	**M6**	**36 mon.**	**D1,2,3,5,6.2,8,9,10,11**

Project Title and Work Package(s) to which it is related: "Exploring the top-Higgs connection using spin correlations in multi-lepton final states" (related to WP 1,2,3,5,6,7,8,9,10,11)

Objectives: In this dissertation, the couplings of the Higgs boson and its CP nature will be further studied, in particular the channel with Higgs decay to two W bosons, produced in association with two top quarks. Focus will be on reconstruction of final states with more than two leptons, benefiting from the supervisor's expertise in reconstruction methods. Deep Learning algorithms will be explored for the reconstruction. This reconstruction will be beneficial to the full ETN and beyond. Angular variables will be studied in order to extract CP information about the Higgs boson. These will be measured differentially and used as input to the overall global fit.

Expected Results: Multilepton event reconstruction, Higgs coupling measurements, CP nature of the Higgs, differential distributions and input information for the global fit.

Planned secondment(s):
1) A first secondment in Madrid for 4 months, supervised by J.-A. Aguilar-Saavedra, in the 2nd year CERN, working on a phenomenological study of using spin correlations to explore CP in multilepton ttH;
2) A second secondment of 3 months at the start of the 3rd year at Bosch to learn applications of machine learning.

Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through Manchester University, **under the supervision of R. Peters**.

<table>
<tr><th>Fellow</th><th>Host instit.</th><th>PhD enrolm.</th><th>Start date</th><th>Duration</th><th>Deliverables</th></tr>
<tr><td>ESR 7</td><td>University of Minho</td><td>Y</td><td>M6</td><td>36 months</td><td>D1,2,3,5,6.2,8,9,10,11</td></tr>
<tr><td colspan="6">Project Title and Work Package: “The Wtb vertex structure in the context of SMEFT framework” (related to WP 1,2,3,5,6,7,8,9,10,11)</td></tr>
<tr><td colspan="6">Objectives: The main objective of this project/dissertation is to use a combined analysis ttbar and single top events (produced through the Wt-, s- and t-channel) to study the structure of the Wtb vertex. Several multilepton final states (with 1 or 2 being) and different flavors (electrons and muons in the final state) will be exercised simultaneously, as signal regions. Multi-dimensional distributions are expected assuming complex Wilson coefficients.</td></tr>
<tr><td colspan="6">Expected Results: Joint analysis of ttbar and signal top events and inputs for the global SMEFT fit.</td></tr>
<tr><td colspan="6">Planned secondment(s):
1) A first secondment at CERN for 4 months, supervised by A.Onofre, in the second year, participation in the global fit of analysis and results discussion;
2) A second secondment of 3 months at the start of 3rd year at Bosch to learn about the full optical bonding system and machine learning techniques.</td></tr>
<tr><td colspan="6">Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through University of Minho, under the supervision of A. Onofre.</td></tr>
</table>

<table>
<tr><th>Fellow</th><th>Host instit.</th><th>PhD enrolm.</th><th>Start date</th><th>Duration</th><th>Deliverables</th></tr>
<tr><td>ESR 8</td><td>Comenius University</td><td>Y</td><td>M6</td><td>36 months</td><td>D2,3,5,6.2,8,9,11</td></tr>
<tr><td colspan="6">Project Title and Work Package(s) to which it is related:
“Boosted production of Higgs bosons and top quarks at the LHC” (related to WP 2,3,5,6,7,8,9,11)</td></tr>
<tr><td colspan="6">Objectives: The objective of this package is to study the production of boosted objects (Higgs boson, top quarks and W bosons) in the boosted regime at the LHC. The study of properties of the structure of jets and a comparison between the resolved regime with the boosted regime in order to gain sensitivity in terms of physics observables, is the main objective of the project.</td></tr>
<tr><td colspan="6">Expected Results: Multijet reconstruction in very busy environments, reconstruction of observables for the SMEFT global fit.</td></tr>
<tr><td colspan="6">Planned secondment(s): 6 months at CERN, supervised by S.Tokar, in the second year, participation in the global fit of analysis and strategy discussion. A non-academic secondment is available to the student, additionally.</td></tr>
<tr><td colspan="6">Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through Comenius University, under the supervision of S. Tokar.</td></tr>
</table>

<table>
<tr><th>Fellow</th><th>Host instit.</th><th>PhD enrolm.</th><th>Start date</th><th>Duration</th><th>Deliverables</th></tr>
<tr><td>ESR 9</td><td>University of Freiburg</td><td>Y</td><td>M6</td><td>36 months</td><td>D2,3,5,6.2,8,9,10,11</td></tr>
<tr><td colspan="6">Project Title and Work Package(s) to which it is related: “Precision measurement of the top-quark mass in $t\bar{t}$-events”, (related to WP 2,3,5,6,7,8,9,10,11)</td></tr>
<tr><td colspan="6">Objectives: In this project/dissertation, the precision of the top-quark mass should be further improved, by focusing on the dominant jet energy scale and signal modelling uncertainties. The improvement of these uncertainties will be beneficial for all data analyses of the ETN. Furthermore, badly reconstructed events should be removed using Machine-Learning techniques such as boosted decision trees (BDTs) and deep neural networks (DNN). This involves the development of a DNN event reconstruction tool.</td></tr>
<tr><td colspan="6">Expected Results: Precision measurement of the top quark mass, General reconstruction tool for top-quark and Higgs boson events.</td></tr>
<tr><td colspan="6">Planned secondment(s):
1) A first secondment at CERN for 6 months, supervised by A.Knue, in the second year, participation in the global fit of analysis and results discussion;
2) A second secondment of 3 months, at the start of the 3rd year, at Bosch to learn application of machine learning.</td></tr>
<tr><td colspan="6">Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through Freiburg University, under the supervision of A. Knue.</td></tr>
</table>

<table>
<tr><th>Fellow</th><th>Host instit.</th><th>PhD enrolm.</th><th>Start date</th><th>Duration</th><th>Deliverables</th></tr>
<tr><td>ESR 10</td><td>Palacky University</td><td>Y</td><td>M6</td><td>36 months</td><td>D2,3,5,6.2,8,9,11</td></tr>
<tr><td colspan="6">Project Title and Work Package(s) to which it is related: “Exploring new methods for top quark reconstruction at the LHC” (related to WP 2,3,5,6,7,8,9,11)</td></tr>
<tr><td colspan="6">Objectives: The main objective of this project is to study and compare reconstruction methods of top quark reconstruction algorithms in resolved and boosted regimes and explore methods to improve the reconstructed mass line shape, including dedicated studies on performance of physics observables in terms of correlations between detector, particle and parton levels, and in unfolding, with implications for the SMEFT global fit in preparation. Also to develop ML techniques related to boosted objects tagging and background rejection.</td></tr>
<tr><td colspan="6">Expected Results: Develop precise and improved methods for measurements of the top quark line shape, also sensitive to physics beyond the SM.</td></tr>
<tr><td colspan="6">Planned secondment(s): 6 Months to CERN, supervised by J.Kvita, in the second year, participation in the global fit of analysis and results discussion. A non-academic secondment is available to the student, additionally.</td></tr>
<tr><td colspan="6">Enrolment in Doctoral degree(s): Ph.D. enrolment and degree through Palacky University, under the supervision of J. Kvita.</td></tr>
</table>

Fellow	Host instit.	PhD enrolm.	Start date	Duration	Deliverables
ESR 11	University of Brasov	Y	M6	36 months	D3,4,5,6.2,8,9,10,11
Project Title and Work Package(s) to which it is related: “Machine learning based optical monitoring system”, (related to WP 3,4,5,6,7,8,9,10,11)					
Objectives: The objectives associated to this project/dissertation relates to the development of optical systems, fully integrated with dedicated front end electronics, for optical detection and pattern reconstruction, using Machine Learning techniques. Within this project several different training programs can be performed in: (1) front-end-electronics; (2) image processing and analysis; (3) reconstruction of image patterns through the use of ML and artificial intelligence.					
Expected Results: A fully integrated ML system (hardware+software).					
Planned secondment(s): 1) Academic secondment of 5 months at CERN, supervised by M.Ivanovici, in the second year; 2) A second secondment of 5 months at Bosch, supervised by A.Onofre, in the third year.					
Enrolment in Doctoral degree(s): Joint Ph.D. enrolm. and degree through UTBv University and UM, **under the joint supervision of M. Ivanovici and A. Onofre**.					

3.2 Appropriateness of the management structures and procedures

The experience, accumulated over the years, on management of research groups, LHC experiments and committees, research and teaching institutions and several international committees, allowed to develop a clear and robust model of the LHCnet organization, decision making, progress monitoring, and risk assessment.

3.2.1 Network organisation and management structure

The main decision-making body of the network is the **Supervisory Board** (**Section 3.2.2**), which will be responsible for making sure the Consortium respects the rights and obligations set out in the Consortium Agreement (including all terms specified for Intellectual Property Rights) and the Grant Agreement. The **Coordinator** of the network will be accountable to the EC for achieving the scientific, training, and dissemination goals of the network, and managing its budget. He will be responsible for all the communication between the network and the EC and will be assisted by an **Administrator** to be hired by the network (50% FTE) who will provide the link with the UM’s Project Support Office (GAP) for technical support. At the Consortium level there will be a **Deputy Coordinator** who will ensure the research activity follows the highest standards of quality and integrity. In the unlikely event of misconduct (misuse of information and funds, falsification, etc.) and disciplinary measures would have to be taken, the Deputy Coordinator would consult the participating organizations and their internal structures and procedures to deal with such situations and, in case of need, a sub-panel of the Supervisory Board would be drawn and chaired by one of the Scientists in Charge. The members of this panel would be agreed by the **Project Management Board (PMB). The PMB is chaired by A. Knue**, is composed by the Coordinator, the Deputy Coordinator, and the Scientists in charge of each Beneficiary. The **Financial Management Team (FMT)** will be composed of the Coordinator, the Deputy Coordinator, the Administrator, and a representative of the UM’s financial department. The FMT will be responsible for distributing the funds to each of the Beneficiaries and for organizing the financial reporting to REA. Each Beneficiary will be responsible and accountable for the budget assigned to its team, following the terms expressed in the Grant Agreement. The recruited ESRs will form the **Students Research Assembly (SRA)**. The SRA will elect representatives of the students to the Supervisory Board.

3.2.2 Supervisory board

The **Supervisory Board (SB) is composed of the Chair (Coordinator, A. Onofre, UM), the Deputy-Chair (Deputy-Coordinator, R. Peters, UMAN), the scientists in charge of the other beneficiaries and partners, as well as two representatives of hired ESRs, appointed by the SRA**. The training activities of the network are coordinated by the SB, which will analyse the network activity for the periodic, progress, and final reports. Decisions will preferably be made under the principle of maximum consensus. The Chair and Deputy Chair will moderate the discussions in case of conflict. If no agreement is found, the decision will be by a simple majority of the members of the SB. If there is still deadlock, the SB Chair will have the casting vote. The SB will meet at least twice per year (once at the annual Network Meeting).

3.2.3 Recruitment strategy

The advertisement of the long- and short-term studentships will be done by all institutions involved in the network. While we will use services like InspireHEP and dedicated job-websites from the ATLAS and CMS experiments, we will also employ our personal networks within the particle physics community. This will allow to reach a vast number of possible candidates. The advertisement will be done in accordance with the formal rules of the different institutes while taking into account the equality measures that the different universities and institutes have implemented. For the application, the candidates need to provide a CV, their transcript of academic records, a short essay about their research interests, and two recommendation letters. A **Recruitment Team (RT), Chaired by Chiara Mariotti**, will be responsible for the coordination of the recruiting process. The goal is to have the positions filled by month 6, following the start of the network. In order to simplify the recruitment procedure, the scientists in charge of each Beneficiary will be part of the RT. The expected timeline for the recruitment is the following:

- **Month 2:** Opening of all positions throughout the different websites;
- **Month 3:** Applications will be collected from the different websites;
- **Month 4:** Selection of candidates. The RT will make the first selection and will match the candidates to the recruiting partners;
- **Month 5:** Candidates interviews. A subset of the RT, including **the Chair and the Coordinator of the network and expected supervisors will form the interview team**. These interviews can be performed through video-conference system or Skype, as needed.
- **Month 6:** Start the recruitment.

Throughout the different stages of selection, the RT will monitor gender balance. This balance should also be reflected in the interview teams.

3.2.4 Progress monitoring and evaluation of individual projects

All beneficiaries in the network have a long track-record in teaching and supervising students. As the work is developed in large collaborations at the LHC, the ESRs will have additional input and training within these collaborations. Each ESR will have a mentor from a different institute in the network, so that in case of problems between the ESR and his/her supervisor he/her has the possibility to speak to someone outside their university. This is particular useful during the secondment training periods. A regular dialogue with the mentor is foreseen. Each ESR will have a clear research plan, defined together with their supervisor at the beginning of their PhD. The progress will be discussed regularly with the supervisor and the research plan adapted accordingly if needed. This will allow to monitor the development of the research project and identify and solve potential problems that may have been missed in the day-to-day work. The overall monitoring of the training programme will be performed by the SB. Should difficulties appear during the process, the ESR can contact the student representatives to bring the problem to the attention of the SB.

3.2.5 Risk management at consortium level

The main risks in the implementation of our network **are listed in Table 3.2**, mainly affecting the recruitment and realisation of ESRs. If problems within one single team arises, it will either be solved internally or can be brought to the PMB and RT.

Table 3.2a Implementation Risks

Risk No.	Description of Risk	WP Nr.	Proposed mitigation measures
R1	Delay in recruitment for long-term ESRs	WP6	● Short delay (few months): simply adjust timelines; ● Longer delay (about 6 months or more): Beneficiary in question has to provide the additional funding necessary for the completion of the PhD. Money that has not been used will be used for the short-term studentships.
R2	Not enough interested candidates for short-term ESRs	WP7	Two different actions will be taken: ● Personally contact suitable students and re-advertise; ● Already running short-term projects could be extended if candidate is interested.
R3	Long-term ESR leaves project prematurely without completion of PhD	WP6	Similar to R1: If this happens in the first few months, the position can be simply re-advertised and the beneficiary might need to provide some extra funding for the completion of the project. If the student leaves in the later stages of his/her project, the funding can be used for the short-term studentships.

3.2.6 Intellectual Property Rights (IPR)

Intellectual Properties Rights were discussed in **Section 2.3.2**. The network software tools and packages will be distributed under Open Source licenses, for use in academia. Intellectual property will be defined within the

Consortium Agreement, at the start of the network. More specific issues related to the non-academic secondments will be negotiated with the Partners at the start of the network, including the necessary reporting back to the network of the achievements obtained by the ESRs. Clear agreements, in the form of contracts, similar to what was done for the "Optical Bonding" CA, will be in place between Beneficiaries and Partners for the non-academic secondments.

3.2.7 Gender and equality aspects

Gender and equality aspects are very important to consider. The low number of female students in physics decreases further for all following career levels. We would like to improve on the current status in several aspects. To start at the most basic level, a large focus of our outreach programme is the interaction with high-school students, where we will motivate female students to think about a career in physics. It is furthermore crucial to proactively contact female candidates and encourage them to apply to the advertised PhD positions in our network. Furthermore we want to create a family-friendly atmosphere which allows both women and men to take parental leave. This furthermore entails to allow for flexible working hours both for ESRs and postdocs with parental responsibilities. Moreover, we want to strongly encourage students from developing countries to take part in our network schools. Our ambition is to allow any student or postdoc with an interest in our research to benefit from the training we provide.

3.2.8 Data management plan

The data management is based on Open-Access as stated in **Section 2.3.2**. The deliverables in the form of software packages, will be distributed worldwide through dedicated web pages with supported repositories like HepForge (http://www.hepforge.org) or Wiki pages, commonly used by the LHC experiments and the theoretical community. They will be distributed under Open Source licenses, for use in the academic framework. The deliverables in the form of publications will be published in Open-Access international journals, with a repository link and a digital object identifier (DOI).

3.3 Appropriateness of the infrastructure of the organisations

All beneficiaries have been working in theoretical or experimental high energy physics for a long time, and have the necessary infrastructure in hand to allow for a successful implementation of the research projects. They will provide office and laboratory space as needed, as well as access to computing facilities and access to the WLCG computing grid. All long-term and short-term ESRs will be embedded in the working groups at the respective institutes, which will provide additional training in the form of local lectures, tutorials, and seminars. In addition, ESRs will have access to the broader training programmes of the universities, such as career training or rhetorical training courses. The academic partner organisations will also provide office space and access to computing facilities and were chosen to provide additional expertise for the academic secondments of the long-term ESRs. For the short-term ESRs, projects between 3 and 6 months that contribute to the overall network research plan. They will furthermore benefit from the training programme, for example in the annual schools, and take part in the network meetings. The non-academic partner organisation will host the non-academic secondments and bring additional training and expertise into the programme. The application of the obtained machine-learning techniques to industrial problems and the interaction with an industrial partner will equip the ESRs with additional skills and give them a further outlook on potential future career choices. Since only the long-term ESRs will be seconded at Bosch, we will invite representatives of the company to the annual schools share with the students the projects and potential job opportunities available in the non-academic sector.

The annual schools will be hosted by three different institutions who have ample experience with the organisation and running of meetings and summer schools. Experimental Particle Physics at VUB is organised within the context of the Interuniversity Institute for High Energies (IIHE), the largest high-energy physics institute in Belgium, with around 100 members. They are co-organisers of the annual Belgium-Dutch-German school in particle physics (http://bnd-graduateschool.org/) with around 50 participants, i.e. a two-week school to introduce PhD students in advanced experimental and theoretical topics of particle and astro-particle physics. In 2016 they also organised the CERN Computing School with around 65 participants (https://indico.cern.ch/event/502875/) on topics highly relevant for ITN LHCnet. VUB is well placed to lead the organisation for the ESRs in LHCnet to participate to a first introductory school. Since the project at the TU Brasov will focus on the development of an optical monitoring system using ML, this university will host the second annual school. During this school, the

ESRs will learn more about the application of ML techniques and prepare them for the non-academic secondments at Bosch. The third annual school will be hosted by Prof. Passarino at the University of Torino, which was a beneficiary in the HiggsTools training network and organised the Higgs Couplings conference in 2014. During this final annual school, the focus will be on the interpretation of the measurements performed. The network meetings will be hosted by six beneficiaries which all have the experience and the resources to host such meetings. Three of the network meetings will be directly followed by career training events for the ESRs. For this training, the professional services of the three universities will be employed, to offer a well-rounded programme for the current job market.

3.4 Competences, experience and complementarity of the participating organisations and their commitment to the programme

3.4.1 Consortium composition and exploitation of participating organisations' complementarities

The composition of our consortium is a big asset for the network program proposed. Having both theoretical as well as experimental researchers as beneficiaries and partners allows to bundle expertise in a beneficial way to provide an exceptional and broad training programme that no single institute would be able to provide on its own. For the research projects themselves, the combination of complementary skill sets is of utmost importance. In discussion with the theory experts we will uncover the most interesting observables sensitive to SMEFT operator effects on our measurements. At the same time, the collaboration between the different experimental teams allows to take correlations between observables and systematic uncertainties fully into account without unneeded approximations. Each improvement made on the experimental side (for example better Monte Carlo tuning, improvement on the jet definition or b-jet identification) will be beneficial for the network as a whole. The development of common tools such as deliverables D1, D2, and D3 avoids duplication of work and will combine the technical know-how of all researchers in order to develop the best framework possible. The projects are connected both on a technical level and by the underlying physics processes. By having academic and non-academic secondments, the ESRs can obtain additional skills and work in different research environments. At the same time ESRs bring their own expertise and skills to other working groups, which will profit from this exchange of ideas as well. The complementarity of the consortium members will allow the LHCnet to educate the next generation of well-rounded researchers who will be proficient in theoretical and experimental particle physics and have a comprehensive training in statistical methods, programming, and management skills, which will equip them with the perfect skill set for their future careers, academic or non-academic.

3.4.2 Commitment of beneficiaries and partner organisations to the programme

All beneficiaries are committed to the implementation of the network program presented here. They will contribute their own working time, research, and computing facilities, as well as the organisation, design, and implementation of the comprehensive training program.

The partner organisations will be strongly involved in the supervision and hosting of the secondments and short-term ESRs, for which they will provide the necessary research and computing facilities. They will furthermore contribute to the annual schools and network events, by contributing to the training and education via lectures or tutorials.