Brussels, 24 October 2016

COST 107/16

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "Vector Boson Scattering Coordination and Action Network" (VBSCan) CA16108**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action Vector Boson Scattering Coordination and Action Network approved by the Committee of Senior Officials through written procedure on 24 October 2016.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA16108
VECTOR BOSON SCATTERING COORDINATION AND ACTION NETWORK (VBSCan)

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. "Rules for Participation in and Implementation of COST Activities" (COST 132/14);
b. "COST Action Proposal Submission, Evaluation, Selection and Approval" (COST 133/14);
c. "COST Action Management, Monitoring and Final Assessment" (COST 134/14);
d. "COST International Cooperation and Specific Organisations Participation" (COST 135/14).

The main aim and objective of the Action is to investigate the Vector Boson Scattering (VBS) process and its implications for the Standard Model, by coordinating existing theoretical and experimental efforts in the area and by best exploiting hadron colliders data, thereby laying the groundwork for long-term studies of the subject and creating a solidly interconnected community of VBS experts. This will be achieved through the specific objectives detailed in the Technical Annex.

The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 32 million in 2016.

The MoU will enter into force once at least five (5) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14.

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OVERVIEW

Summary
The ATLAS and CMS collaborations at CERN recently discovered a new resonance, matching the features of the Higgs boson, the missing piece of the Standard Model of particle physics. Yet, several fundamental issues remain unsolved: gravitational interactions are not unified with other forces, no valid candidates exist for dark matter, no explanation was found for the relative abundance of matter over anti-matter in the Universe. These open issues call for a more general theory, introducing new phenomena which might be visible during future measurements, which are among the main objectives of current and future particle colliders. Vector Boson Scattering at hadron colliders is the ideal testbench for such new processes, as the Standard Model predicts it to be highly suppressed through interference effects, and a variety of new physics scenarios may disturb this delicate balance. At the same time, these measurements are very challenging, because of the overwhelming backgrounds, the tiny effects investigated, and the required precision of theory predictions. Only a very coordinated and thorough effort involving all the stakeholders will allow to reach the best sensitivity from the data.

This COST Action will connect all main players studying Vector Boson Scattering at hadron colliders, gathering the solid and multidisciplinary community needed and aims to become the worldwide reference on Vector Boson Scattering, bringing together experimentalists, theorists, and statisticians. The capacity of the community will be maximised with a thorough inclusiveness campaign, targeting early career investigators, gender balance and maximal geographical openness.

Areas of Expertise Relevant for the Action	**Keywords**
● Physical Sciences: Particle physics (theory) ● Mathematics: Statistics	● particle physics ● hadron colliders ● electroweak symmetry breaking ● beyond standard model ● big data analysis

Specific Objectives
To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination
● A standard for the definition of Vector Boson Scattering signal and background processes to be used in calculations and experimental analyses will be set.
● Signal and background processes with be described a significantly better precision than available nowadays, with next-to-leading precision in the strong and electro-weak perturbation theory of the Standard Model.
● Means will be developed for the isolation of the scattering of longitudinal vector boson modes and establish a protocol to be followed for theoretical predictions and the interpretation of experimental results, which will allow the measurement of the longitudinal component at the High Luminosity Large Hadron Collider.
● A reference parameterisation for beyond-the-Standard-Model physics effects in Vector Boson Scattering will be determined, next-to-leading precision in the strong and electro-weak perturbation theory of the Standard Model.

● Novel reconstruction algorithms will be developed, for the final state particles configuration characteristic of the Vector Boson Scattering case, maximising the selection efficiency while rejecting instrumental backgrounds due to simultaneous particle collisions and false positives in the detector.
● Identify the measurements best suited for the determination of the Standard Model cross sections for Vector Boson Scattering processes, and determine the best algorithms to enhance the signal component over the background.
● Develop effective ways to combine the experimental and theoretical advances into recommended standards for Vector Boson Scattering analyses, allowing direct comparison among experiments and theoretical forecasts.
● Define milestones for Vector Boson Scattering studies at the end of the Large Hadron Collider Run 2 data taking, including accuracy targets, such that they are coherent between the experimental analyses and the theoretical calculations.
● Define the necessary features in theoretical calculations to achieve the Large Hadron Collider Run 2 data accuracy targets, and coordinate the implementation and validation of these theoretical features.
● Define the procedure to combine separate experimental results obtained by the ATLAS and CMS collaborations.

Capacity Building
● Consolidate the existing collaborations in the frame of a single coherent structure and create a long term community that will survive the end of this Action.
● Significantly improve the gender equality in the collaboration, with respect to the average distribution in the high-energy physics field.
● Include relevant researchers from COST Near Neighbor Countries (NNC) and COST International Partner Countries (IPC) in the Action.
● Transfer knowledge in terms of exchange of expertise, scientific tools and achievements, human resources and experience.
● Promote the communication with researchers with expertise going beyond the vector boson scattering domain, to get a broader point of view within the high-energy physics landscape.
● Promote Early Career Investigators visibility and inclusion in the vector boson scattering community, for example enabling them to present their activity at the Network meetings.
● Prepare competitive EU researchers for a fruitful career in an international environment both from the scientific and managerial point of view, for example by encouraging them to take leading positions in the Action.
● Maximise job opportunities for PhD students and early career investigators, by deploying an effective set of instruments, such as a database of job offers within the Network.
● International integration of researchers from COST Inclusiveness Target Countries (ITC).
● Disseminate the results of the Action activities to the scientific community and to the general public.

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. Challenge

1.1.1. Description of the Challenge (Main Aim)

The Standard Model (SM) of particle physics describes the known fundamental particles and their interactions. Discoveries and precision measurements carried out in the past at particle accelerators, like the Large Electron-Positron collider (LEP) and the Tevatron, confirmed the SM to great precision at their operating energies. Recently, the Large Hadron Collider (LHC) at CERN (European Organisation for Nuclear Research) made it possible to discover the Higgs boson, which was the last missing piece of the SM since its formulation in the mid-seventies, and triggered the Nobel Prize in physics awarded to F. Englert and P. Higgs in 2013.
Despite the SM success, important questions about the underlying nature of our Universe remain unsolved. The existence of new dark matter is expected according to cosmological evidence, but what is it composed of? What is the origin of neutrino masses? What is the reason for the predominance of matter over antimatter in the Universe? Will it be possible to integrate also the gravitational interactions in a single Quantum Field Theory describing all aspects of Nature? Is the discovered Higgs boson in line with the SM prediction? Are there new symmetries and new particles, around the corner, i.e. at energies accessible to the forthcoming data taking at hadron colliders? These questions, together with the tantalising deviations in the di-boson and di-photon spectra observed by the LHC experiments, push the current experiments at hadron colliders to search for new particles directly and to investigate new processes with known particles.
The answers may be found at the heart of the SM, the breaking of the electroweak symmetry (EWSB): with this mechanism vector bosons acquire mass through their coupling to the Higgs field. At the same time, EWSB also rules the scattering of vector bosons (VBS, vector boson scattering), avoiding its divergence at high energy. The rate of occurrence of VBS processes is predicted by the SM to be very low due to cancellations of different contributions. Processes related to new physics can disturb this delicate balance and lead to potentially large enhancements of the VBS rate, making it the ideal process for a model-independent test-bench of new physics at an energy scale never investigated before.
Vector Boson Scattering Coordination and Action Network (VBSCan) will cast a spotlight on VBS, coordinating all the existing theoretical and experimental efforts into a single coherent Network. This Action will exploit in the best possible way data that will be delivered in the forthcoming years by hadron colliders. It will lay the groundwork for long-term studies of the subject, creating a solidly interconnected community of experts focused on VBS, which will be one of the flagship analyses of the LHC legacy.
Our studies will address in particular the scattering of longitudinally-polarized vector bosons, which is maximally sensitive to any new phenomena in the EWSB physics. First experimental results on VBS obtained at the LHC have a very low precision, due to the rarity of VBS processes. The forthcoming data will grant us much better precision in the near future. Still, the effects searched for are expected to be very small, therefore sophisticated analysis strategies and tools (e.g. deep-learning techniques) as well as precise predictions for VBS reactions will be required. VBSCan will give a new impulse to the study and promote discoveries by enhanced collaboration between different experiments and the theoretical community, effectively exploiting the currently scattered expertise to drive the development of new experimental techniques as well as theoretical advances.

1.1.2. Relevance and timeliness

The recent discovery of a Higgs boson has invigorated the study of EWSB, as the presence of the Higgs boson indicates that this SM mechanism is working, at least as a first approximation. This observation has produced a notable turn-over in theoretical models which posit effects beyond the SM (BSM): models that cannot accommodate the newly discovered particle have been discarded, while new ones are invented that embed the Higgs boson.
While the study of the Higgs resonance itself can help to distinguish such models from the SM, many of them are also expected to leave tell-tale signs in VBS processes, the study of which is still in its infancy. Currently operating colliders, the central point of the European strategy for particle physics, promise an abundance of data which will allow a detailed study of these processes, ultimately testing the SM at high precision or possibly hinting at new physics. A prompt development of novel analysis techniques and improved theoretical predictions will be necessary to exploit these datasets with maximal effectiveness.
Beyond the immediate future of currently running experiments, VBS studies will also be a major topic at future facilities currently in the planning phase. Experience gained on the context of this Action will be valuable in the performance projections for these future facilities, ultimately strengthening the physics case and preparing the European community for a leading role in exploiting the capabilities (and results) of current and future colliders.

1.2. Specific Objectives

1.2.1. Research Coordination Objectives

The theoretical understanding of VBS:

- Set a standard for the definition of VBS signal and background processes to be used in calculations and experimental analyses.
- Describe signal and backgrounds with a significantly better precision than available nowadays.
- Develop means for the isolation of the scattering of longitudinal vector boson modes and establish a protocol to be followed for theoretical predictions and the interpretation of experimental results.
- Determine a reference parameterisation for BSM physics effects in VBS, with unprecedented precision in the calculations.

The development and implementation of the data analysis:

- Develop novel reconstruction algorithms of the final-state particles dedicated to the VBS case, maximising the selection efficiency while rejecting instrumental backgrounds due to simultaneous particle collisions and false positives in the detector.
- Identify the measurements best suited for the determination of the SM cross sections for VBS processes.
- Determine the best algorithms to enhance the signal component over the background.
- Develop effective ways to combine the experimental and theoretical advances into recommended standards for VBS analyses, allowing direct comparison among experiments and theoretical forecasts.

Definition of the protocols for the results extraction:

- Define milestones for VBS studies at the end of the LHC Run 2 data taking, including accuracy targets, such that they are coherent between the experimental analyses and the theoretical calculations.
- Define the necessary features (e.g. level of perturbative calculations) in theoretical calculations to achieve these accuracy targets.
- Coordinate the implementation and validation of these theoretical features.

- Define the procedure to combine separate experimental results.

1.2.2. Capacity-building Objectives

- Consolidate the existing collaborations in the frame of a single coherent structure.
- Significantly improve the gender equality in the collaboration.
- Include COST Near Neighbor Countries (NNC) and COST International Partner Countries (IPC) in the Action.
- Create a long term community that will survive the end of this Action.
- Transfer knowledge in terms of exchange of expertise, scientific tools and achievements, human resources and experience.
- Promote the communication with experienced researchers from broader areas.
- Promote Early Career Investigators (ECI) visibility and inclusion in the VBS community.
- Prepare competitive EU researchers for a fruitful career in an international environment both from the scientific and managerial point of view for example through intensive use of Short Term Scientific Missions (STSM).
- Maximise job opportunities for PhD students and ECI.
- International integration of researchers from COST Inclusiveness Target Countries (ITC), which are otherwise limited by economic conditions.
- Disseminate the results of the Action activities to the scientific community and to the general public.

1.3. Progress beyond the state-of-the-art and Innovation Potential

1.3.1. Description of the state-of-the-art

The SM predicts interactions between three or four weak vector bosons. While the triple boson interaction was scrutinized intensively in the last thirty years, evidence for quartic boson interaction was observed only recently for the first time in VBS processes. This observation has opened the new so far unexplored testing ground for SM physics allowing to set limits or discover effects of new physics in quartic boson interactions. However, the significance of these measurements is so far limited by the small number of VBS events observed. As a consequence, only simple, cut--based analyses were performed, lacking more powerful multivariate techniques. Particles produced in VBS events are identified by detectors based on reconstruction algorithms which have never been optimised for the VBS case. As a consequence, the resulting measurements are commensurate in accuracy with the existing calculations. At the same time, the community interested in VBS is very fragmented and connected only through local informal links, typically not supported by official funding programs, which badly affects the generality of the published results.

From the experimental point of view, existing studies have been focused entirely on leptonic final states, which are the easiest to analyse, but only represent a small fraction of all available decay modes. For each final state, the high particle multiplicity in the VBS case, together with special features of these events (like the important role played by longitudinally-polarized vector bosons, or the characteristic distribution of the energy flow in the event) call for dedicated algorithms to enhance the capability of separating signal events from the various backgrounds present at hadron colliders. Such algorithms should be robust against pile-up, which is the random overlap of several particle collisions in the same recorded event at hadron colliders.
Particles to be identified are charged leptons, jets from the decay of vector bosons, jets from the scattering process, and neutrinos, which at hadron colliders are detected only as energy imbalance in the plane orthogonal to the proton beam's direction (called missing transverse energy, MET). High energy charged leptons can typically be well identified. Jet identification algorithms exist, while no big effort has been so far devoted to separating jets originated by gluons from the ones originated by quarks, which would lead to a big advancement in the VBS signal segregation. Jets

produced by high-energy vector bosons are so collimated as to overlap in the detector. State-of-the-art techniques address this issue, but do not exploit the knowledge of the internal structure of jets to derive information on the polarisation of the vector bosons, which would significantly help in isolating longitudinal VBS. No specific MET identification has ever been implemented in the high particle multiplicity case: dedicated algorithms could improve the resolution on its magnitude. VBS is characterised by low additional QCD activity in the signal events, because all the involved particles undergo electroweak (EWK) interactions. Therefore, a precise measurement of QCD energy flow is a powerful tool to reduce background contamination. So far, only simple algorithms for additional QCD activity veto exist, while more sophisticated ones would allow for significant background reduction.
Eventually, all these pieces of the VBS puzzle have never been optimally combined to disentangle the signal from the backgrounds, for example embedding them in deep-learning based event shapes, which can be used in a multi-dimensional fit to the data.

Theoretical predictions are built on perturbation theory, which produces results as sums of terms, each of them corresponding to increasing precision in the calculation, both for the strong force (QCD) and the electroweak one (EWK). The leading order (LO) one is in general well known for any process, while it is possible to generate simulated physics events at the next to leading order (NLO) only for a limited number of processes. At the same time, predictions at NLO or beyond are typically required for a good agreement between theory and data.
Despite the recent achievements in the automation of NLO computations (at least as far as QCD calculations are concerned), the large number of external particles in VBS reactions makes the inclusion of NLO corrections for such processes quite challenging. At present QCD corrections are available only for VBS processes with leptonic decays of the vector bosons. Only in some cases they can be interfaced and matched with parton shower programs. The NLO description of the background processes, from which VBS events need to be extracted, is only partial.
Completely lacking so far are calculations at the NLO precision in the EWK sector of the theory. These are expected to be potentially large in the energy domain of present and future hadron colliders, affecting event rates and modifying the shape of kinematic distributions significantly. Only explicit calculations of the dominant and, ultimately, subdominant EWK terms to VBS processes will pave the ground for true precision analyses at the high energy regime of VBS.
With this in mind, one of the main motivations for a careful study of VBS processes lies in the possibility of discovering some deviations from SM expectations, signalling new physics. A parameterization of modifications to the SM must therefore capture the expectations of large classes of BSM scenarios. The most popular example is the Effective Field Theory (EFT) of the SM, which provides a consistent framework that, on the one hand, describes generic deviations from the SM and, on the other hand, can be easily matched to explicit BSM scenarios. One of the measurable effects of the EFT is the modification of the SM couplings (which become “anomalous couplings”). Moreover, the SM EFT would allow to compare and combine the outcome of different experiments (including searches for new resonances and other precision measurements) into a global result.
The EFT is often truncated at LO precision, a fact that is then neglected when testing EFT predictions with real data and can lead to misinterpretations. While different approaches have been proposed to guarantee validity of the EFT expansion, none has been explicitly designed for VBS and it is fair to say that none is universally accepted. Moreover, BSM physics is characterized by new couplings, and until we fully understand the size of those and the additional symmetries of the theory it is not clear if truncating the EFT at the LO precision offers a good description. For this reason it is necessary to develop a complete BSM perspective, captured in the form of an EFT, possibly with NLO precision, of what deviations from the SM can be expected. At the same time, it is necessary to design the data analyses in such a way as to allow a consistent interpretation in terms of a valid EFT, which requires an agreement amongst the different experimental

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communities which, at present, has not been reached. Finally, a search strategy targeted to the most interesting BSM effects needs to be developed.

1.3.2. Progress beyond the state-of-the-art

VBSCan will leave as legacy important advancements in the field of particle physics, in particular at hadron colliders.

- For the first time ever, a data analysis protocol will be set for the study of the EWSB, fully shared by all the relevant experimental and theoretical stakeholders. This will allow a direct, effective and unambiguous combination of all existing experimental results and their most effective comparison to theory expectations.
- VBS will be studied with unprecedented precision, squeezing out from data any possible indications of new physics in the EWK sector: if BSM physics is within reach it will be found, otherwise stringent constraints will be obtained. Any of these results will be of high relevance for pinning down the nature of EWSB.
- The data analysis procedures will remain documented in the literature and will serve as guideline for future analyses of data collected after the end of this Action.
- A lively, multi-disciplinary and tightly-connected community will continue pursuing VBS analyses also after the end of the Action.

From the theory point of view, the heritage of the Action will be significant.

- The full description of all VBS signals and relevant backgrounds, with the NLO precision in QCD and EWK expansions will be achieved, including quantum interference between the different contributions, and the proper matching to the parton shower.
- EFT calculations for VBS will be developed at the NLO precision both in QCD and EWK. Besides remaining available in the field, these major advancements will serve as an example for other EFT models to be developed in the future.

From the experimental point of view, important advancements will happen as well.

- The development of methods to differentiate the polarisation states of the vector bosons involved in the scattering process will allow the isolation of the most interesting VBS processes, and is likely to be of great use in other areas of experimental EWK physics.
- Improved theoretical description of VBS will help more refined data analysis techniques to be developed on the basis of the more precise predictions we will construct.
- Pile-up resilient algorithms for particle identification, optimised for VBS topology, will be developed and made publicly available, to be exploited also in other domains of interest at hadron colliders.
- Deep knowledge of the energy flow in the events, besides the leading particles produced in the VBS process, will be key in separating signal from background, and will remain as additional capacity for all future analyses at hadron colliders.

From the data analysis point of view, VBSCan will bring significant benefits as well.

- Compared to current analysis, the extensive use of sophisticated multivariate methods borrowed from statistical data analysis will push the sensitivity of VBS beyond the extrapolations from existing studies.
- The statisticians community will adapt existing algorithms, and develop new ones, to the big data samples typical of particle physics, profiting of a new development environment.
- Data analysis techniques adopted in particle physics will spread to the statistics community, possibly bringing new points of view to that field.

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1.3.3. Innovation in tackling the challenge

This Action will address the VBS analysis with a novel approach from several concurrent directions.

- From the experimental side, for the first time ever, the event reconstruction will be fully target-driven, with an optimisation specific to VBS studies.
- Unprecedented collaborations with data analysis scientists will bring new ideas and tools to the final result extraction (for example with advanced deep-learning techniques), and at the same time will induce cross-fertilisation from the particle physics field to the statistics one.
- From the theory point of view, NLO QCD and EWK calculations will be merged into a single prediction both for the SM case and for the EFT one, in the very challenging VBS framework. This will require novel approaches in the technical implementation, to preserve the required accuracy without compromising the results computation practically.

1.4. Added value of networking

1.4.1. In relation to the Challenge

The VBSCan proposers cover most of the knowledge necessary for the success of the Action. The main players in the theory community are involved, together with representatives from the existing experiments at hadron colliders. The most relevant worldwide laboratories are among the proposers, as well as experts from statistical data analysis. Such a wide collaboration in terms of skills and geographical involvement will be the only way to leverage on scattered resources to attain the best worldwide measurement of VBS.

- The strengthened interdisciplinary communication between the experimental and theoretical communities will allow to optimise experimental analyses and theoretical feasibility studies on the basis of all possible sources of backgrounds and uncertainties, and to greatly ease the comparison of BSM theories to existing measurements.
- The network will provide the framework for comparison and combination of experimental results from different experimental groups by recommending common interpretation schemes (e.g. EFT parameterization).
- Coordinated experimental results will allow easy combination effectively maximising the precision in worldwide reference measurements.
- The close collaboration between experimental and theory communities will guarantee that experimental results are published in a form best suited to later reinterpretation in the light of new BSM models.
- Data sharing with statisticians will benefit both the particle physics and statistics communities, generating cross-fertilisation of the fields.
- The inclusion of COST NNC and COST IPC in the Action will strengthen the leading role of Europe in the fundamental particle physics research and will pave the way for a long term community that will survive the end of this Action.
- Our gender balance policy will grant visibility to women as role models, and will bring their contribution to the particle physics world in a more effective way.
- Participation in VBSCan will enhance chances of finding jobs for young scientists through the job offers and candidates database, and staff exchange to build personal contacts.
- The attention to COST Inclusiveness Target Countries (ITC) will fill the gap with the rest of the EU community.

1.4.2. In relation to existing efforts at European and/or international level

Several international efforts tangentially touch upon the topic of VBS. However, none of them has VBS as main focus and they cannot be expected to drive a significant progress in this field. The

relevant experts will be contacted to coordinate the work on VBS to the mutual benefit of this Action and the existing networks.

- The HiggsTools Initial Training Network (https://higgstools.org/WP1) includes VBS studies within a wide range of Higgs-boson related subjects, where it is treated as peripheral.
- The MCNet Marie Curie Initial Training Network (http://www.montecarlonet.org/) deals with particle physics event generators, which includes the VBS process implicitly, but no targeted effort exists to develop or improve tools for VBS specifically.
- The LHC EWK working group, which coordinates LHC experiments and theory for EWK physics, has no dedicated VBS working group and is not involved in studies concerning future projects (https://lpcc.web.cern.ch/lpcc/index.php?page=electroweak_wg).
- The LHC Higgs cross-section working group is not directly studying VBS, but the close relation of VBS and Higgs physics means that relevant experts will possibly be active in both networks (https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG).
- Developers of Monte Carlo programs, theory calculations, and tools for comparisons with data are part of VBSCan proponents, or will be contacted and involved in the project.
- The Action will foster the participation of all the ATLAS and CMS people involved in VBS analyses, as these experiments will be the main source of forthcoming data.

2. IMPACT

2.1. Expected Impact

2.1.1. Short-term and long-term scientific, technological, and/or socioeconomic impacts

- **Scientific impact.**
  - Implement pile-up-resilient particle identification algorithms at hadron collider experiments specific to high-multiplicity events, demonstrating the target-oriented event reconstruction paradigm.
  - Produce a deeper understanding of the EWK sector of the SM with an unprecedented insight, also at very large energies with respect to any existing resonances found so far.
  - Foster the best world combination of experimental results on VBS matters, and the most precise comparison to theoretical calculations thanks to the developed reference protocols.
  - Determine discrepancies between data and SM predictions hinting to the existence of new phenomena, in a model-independent way, with the best precision possible.
  - Verify BSM theories in their impact on the EWSB, with the best accuracy possible.
  - Deliver detailed feasibility studies for VBS at future hadron colliders.
- **Technological impact.**
  - Bring the statistical data analysis into the particle physics domain through the direct involvement of statisticians, boosting the data mining abilities of high energy physicists through new algorithms (e.g. based on deep learning) and a deeper understanding of them with respect to the simple usage.
  - Allow statisticians to access the big data typical of particle physics, to develop the research along new lines designed to adapt to the specific problem of the physics environment, and build novel algorithms to be exported to other fields.
  - Develop new calculation procedures in the frame of theoretical physics, that will then be generalised, embedded into the existing generators and made available to be used in the generation of any processes with NLO precision in the EWK and QCD calculation, also with high particle multiplicity.
- **Socio-economic impact.**
  - Create a multidisciplinary, functional and cohesive network, overcoming the current fragmentation in the VBS community, to remain active beyond this Action.

- Strengthen Europe's leadership in fundamental physics, thanks to the creation of a strong worldwide authoritative community on VBS matters.
- Counteract the current gender imbalance in the fundamental physics field and potentiate less research intensive countries.
- Educate highly-motivated students and young post-docs to leading roles in a research environment, with independent thinking, problem-solving attitude and the capability to work in a competitive international environment.
- Create additional opportunities for VBSCan members, their students and postdoctoral researchers to further boost their career.
- Increase the visibility of individual institutions generating synergies and transversal multidisciplinary collaborations to foster innovation.

2.2. Measures to Maximise Impact

2.2.1. Plan for involving the most relevant stakeholders

The proponents of this Action comprise experts from all experimental collaborations which are currently studying VBS as well as experts from the theory community working in the field. They will use their personal contacts as well as collaboration meetings to recruit additional contributors, also from International Target Countries. Experts currently working on preparatory studies for VBS at possible future accelerators will be involved in the activities as well.
Young talents promotion will be achieved by putting them in close contact with leading groups in VBS, granting them visibility in the scientific community, exposing them to overviews of the most important results in the different subjects, and supporting university internationalisation programs already existing in countries participating to this Action. This will be accomplished through scientific exchanges between ECI and senior experts in the field. ECI will take managing roles in the organisation of workshops and meetings within the Action, and participate to outreach activities with leading positions. Three training schools on VBS subjects will be organised, covering experimental, theoretical and statistical subjects. In this way, VBSCan will train competitive EU researchers capable of taking leading roles in their professional future. To maximise the success of ECI future careers, the Action will also deliver a platform, within its website, to gather job opportunities in the field and a database of job offers and available candidates, to be subscribed by PhDs and postdocs.
This Action will significantly improve the gender equality in the collaboration. Specific measures will ensure the presence of highly qualified women in scientific committees, as speakers at internal workshops and training schools and as leaders of internal working groups. This will put in evidence young and senior role models that, together with specific outreach activities targeting girls, will counteract cultural barriers that prevent women from pursuing a scientific career. Women participation to the various aspects of the Action will be carefully monitored, to ensure they have the same visibility and promotion opportunities as their male peers, boosting the quality and innovation of research. The significant fraction of women amongst VBSCan proposers puts solid grounds to attain these objectives. To counteract the severe limitations in travel that researchers from Inclusiveness Target Countries often suffer for budget reasons, this Action will organise two Yearly Workshops and a Training School in a member Country among the COST ITC, and at the same time will promote scientific missions of ITC ECI to visit VBS experts in their institutions, and vice versa.
VBSCan meetings will be open to the scientific community and widely advertised on the usual communication channels of the experiments, theory and statistics communities, in order to gather researchers from the several institutions worldwide that already showed interest in this Action, and to attract new participants. Results of the activities will be advertised in international conferences and national meetings, and the Training Schools will be open to the scientific community to widen the VBS network towards students and ECI.

2.2.2. Dissemination and/or Exploitation Plan

All the results will be published in highly-ranked open-access peer-reviewed scientific journals, and will acknowledge support by COST. They will also be publicly available on arXiv (www.arXiv.org). Papers covering experimental results will be published in the context of the experimental collaborations, while members of the theory and statistics communities will publish their results individually. In addition we foresee joint publications by VBSCan members on the recommendations and protocols resulting of the Action activities, with the aim of becoming references for the various experimental analyses and measurements interpretations. Besides journal publication, results will be presented at the most relevant international conferences and at topic workshops. The entirety of the activities will be documented in a dedicated website, with a section for the general public and one reserved to the Action participants, making use of wiki-based technology to create a common, global and evolving documentation platform. Mailing lists will also be created to smoothen communication. The website will also contain a detailed directory of experts in the VBS field, to be made available to the scientific community.
VBSCan activities will begin with a kick-off event, where experts from broader areas will be invited to participate. Regular meetings of the working groups will set the pace of the activities and review the results attained. Yearly workshops of the entire Action will be organised in different countries participating to the Action. A mid-term scientific meeting (MTSM) will serve as major review of the activities. STSMs will be planned on a yearly basis and for scientific exchanges to tighten existing links and create new ones, also giving ECI the chance to get in contact with authoritative figures in the field. At the end of the Action, an international conference on VBS matters will be organised, and a handbook will be written, containing the final outcome of the Action activities. Training schools will be organised, addressing Master, PhD students and young postdocs.
VBSCan will promote the scientific culture in the European Union, increasing the interest of the general public towards the fundamental contents of the field. Outreach activities will be targeting school pupils and young students (by means of seminars, hands-on-workshops on data analysis, outreach events in high schools). Dissemination material will be made available electronically on the website and in hand-outs for hands-on-workshops. This material will be also freely accessible for the wide public audience and political decision makers, which will be informed about the scientific targets of the Action, as well as its involvement in issues of public participation. VBSCan will take part in already existing events for dissemination purposes in the local communities of its members.

2.3. Potential for Innovation versus Risk Level

2.3.1. Potential for scientific, technological and/or socioeconomic innovation breakthroughs

VBSCan is firmly rooted in fundamental science, so scientific progress is the main aim. The minimal goal of the work proposed here is the verification of the SM at high precision, especially the EWSB mechanism. This minimal goal would represent significant scientific progress in itself and can be achieved even if some of the work packages cannot be completed.
In the best case, on the other hand, the studies proposed here may discover significant deviations from the SM, such as a modified mechanism of EWSB. This would represent a major breakthrough in fundamental physics. In this case the network supported by this Action will be of particular importance to reap maximal scientific benefits, as the close collaboration of the relevant experts in theory and experiment will be essential.

3. IMPLEMENTATION

3.1. Description of the Work Plan

3.1.1. Description of Working Groups

The objectives of the Action will be addressed by five working groups (WG).

WG1: theoretical understanding	
Main aim	Detailed description of the VBS signal and relative backgrounds in the SM case, as well as EFT modelling of BSM effects.
Tasks & Deliverables	● Coordination of NLO QCD and EWK SM calculations ● EFT definition, and NLO QCD and EWK EFT calculations ● VBS signal definition
Milestones	● First recommendations on signal and EFT definition at the end of year 1, final ones at the end of year 2 ● NLO precision in calculations throughout the Action ● First simulations at energies of future colliders in year 3, final results in year 4
WG2: analysis techniques	
Main aim	Definition of data analysis protocols and agreements to maximise the significance of VBS analyses at hadron colliders, fostering the communication between theory and experiments.
Tasks & Deliverables	● Determination of the best observable quantities for VBS data analysis ● Implementation of advanced data mining techniques in the signal characterisation ● Experimental results publication and combination guidelines
Milestones	● First recommendations on observables during year 1 ● first combination guidelines at the end of year 1 ● Advanced data mining techniques recommendations evolving with time, following the increasing statistical power of collected data ● First prospect studies for future colliders in year 3 ● Final recommendations in year 4
WG3: experimental measurements	
Main aim	Foster the optimal deployment of VBS studies in the hadron collider experiments data analyses.
Tasks & Deliverables	● Promote the development of VBS-specific target-oriented reconstruction algorithms, pile-up-resilient, adapted to high-multiplicity environments ● Foster the deployment of the data analyses in the experiments ● Perform a joint interpretation of the public results in light of the Action knowledge
Milestones	● First tests of dedicated reconstruction algorithms at the end of the year 1 ● First coherent data analyses deployment, following the recommendations of WG1 and WG2, within year 2

	• Updating of the analyses with new data throughout the Action. Final results interpretation in year 4
WG4: knowledge exchange and cross-activities	
Main aim	Knowledge transfer as exchange of expertise, scientific tools and achievements, human resources and experience, spreading the VBS community with new ideas and unconventional thinking.
Tasks & Deliverables	• Organisation of the internal events, STSM coordination • Implementation of the communication tools (website, mailing lists, wiki-based documentation collector, directory of VBS experts) • Outreach • Final Handbook publication • Final Conference organisation
Milestones	• Full website delivery infrastructure, including jobs offers and candidates database, within 6 months • Events organisation and STSM handling well synchronised with the events schedule
WG5: Inclusiveness Policies	
Main aim	Full inclusion of researchers that, for geographical or sociological reasons, might need specific policies to get on the same footing as the rest of the community.
Tasks & Deliverables	• ECI promotion through STSM and as managers of the Action • counteract gender imbalances, also promoting women in manager positions • support members of COST ITC through STSM and organisation of events there
Milestones	• Review of the effectiveness of inclusion policies every six months • organisation of topic discussions on inclusiveness issues during the yearly meetings, the MTSM and the final conference

3.1.2. GANTT Diagram

general meetings		year 1				year 2				year 3				year 4			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Kick-off event (KE)																	
MC Meeting																	
WG Meeting																	
Yearly Workshop (YW)																	
Training School (TS)																	
MTSM																	
Final Conference (FC)																	
WG activities																	
WG1	VBS signal definition																
	EFT recommendation																

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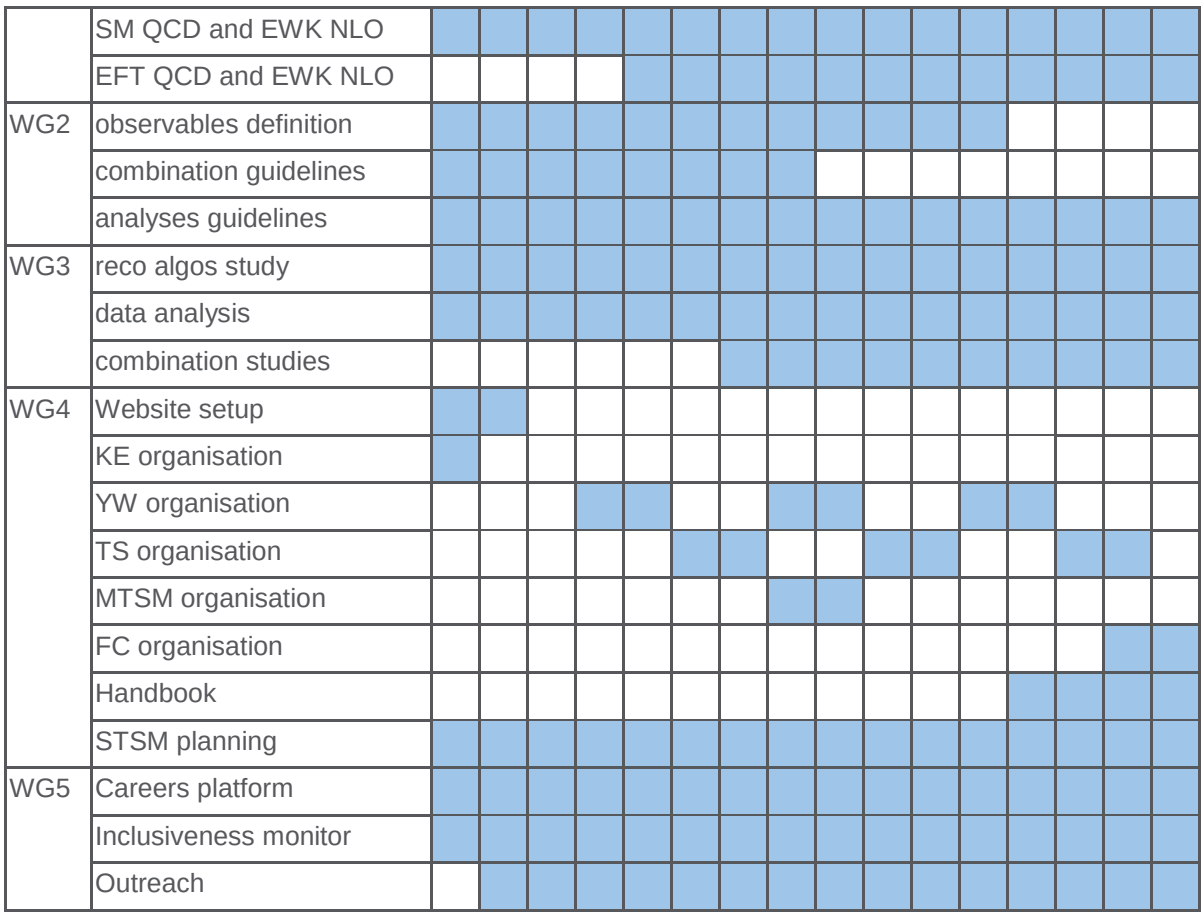

3.1.3. PERT Chart (optional)

3.1.4. Risk and Contingency Plans

The MC chair together with the WG conveners will closely monitor the progress of the work, to identify and mitigate the risks to the success of VBSCan in a timely manner. This approach will ensure that in addition to the risks (and corresponding mitigation plan), the Action is well prepared for unforeseen circumstances. The major internal and external risks are listed in the following tables.

External risk	probability	impact	mitigating action
Underperformance of current particle accelerators.	moderate	moderate	The theory goals of the Action remain unaffected. Management will extend the envisioned timeline for the experimental studies to match the pace of accumulating data.
Underperformance of current particle detectors.	low	moderate	The redundancy of detectors taking data mitigates the risk. The management will optimise partial datasets analysis leveraging on the network capacity.
Funding risks for	low	moderate	VBSCan members will actively take part

upgrades of current accelerators and experiments.		(reduced funds) to high (no funds)	in funding applications in their countries, using the work within this Action to support the importance of VBS studies with upgraded experiments.

Internal risk	**probability**	**impact**	**mitigating action**
Unavailability of key Action members.	moderate	low	The network is already well staffed with relevant experts, to the point where no single member is essential to the Action. A replacement will be elected or appointed for management roles.
Difficulty in involving ECI, ITC in the Action, or in gender balancing.	low	moderate	Targeted campaigns to enrich the Action participation, careful location planning of internal meetings, further reorganisation of the management structure including missing categories of stakeholders.
Delay in the completion of NLO calculations for the SM or for EFT.	moderate	moderate	Temporary comparison between theory and measurements will proceed assuming larger systematic errors. The missing contributions will be introduced as they become available.
Difficulty in finding a single common EFT reference.	low	low	If different BSM models will require specific parameterisations, multiple sets of recommendations will be delivered, to cover all the possibilities.
Delay in exporting statistics tools to the particle physics environment.	low	low	Redistribution of the Action manpower and active recruitment campaign, participation of ECI to training schools to get needed skills.
Delay in implementation of novel analysis techniques.	moderate	moderate	Measurements performed with known analysis techniques will guide the development of new tools.

3.2. Management structures and procedures

The organisation of VBSCan will follow COST rules. It will be governed overall by a Management Committee (MC), chaired by the Action Chairperson assisted by a Vice-Chair, both elected during the kick-off event, who will coordinate all research initiatives. A wide participation in the management will be ensured for ECI, women as well as representatives from COST ITC. Each WG will be coordinated by a WG Leader and a Vice-Leader (VL), elected during the kick-off event, who are responsible for the WG activities in line with the Action strategy (defined by the MC) to achieve the Action objectives. MC will ensure constant communication of the Action with the COST Framework. The operative management work will be executed by a Core Group (CG) within the MC. It will be composed of the Chair, the vice-Chair, the Working Group (WG) leaders, including the coordinators for the STSM and for Inclusiveness Policies.

The leader of WG4 will function also as STSM manager and meetings coordinator within the CG and MC. She/he will prepare the annual plan to be submitted to the MC and appoint organising committees for meetings. She/he will also promote and coordinate STSMs especially within the ECIs. The leader of WG5 will naturally function also as Inclusiveness Policies Coordinator within the CG and MC, including matters regarding young talents, gender balance, ITC issues, job opportunities and outreach. The CG will be responsible for the preparation of all documentation required for the MC meetings. The MC will meet twice a year, in person or by means of virtual meetings. WGs will meet at least twice a year. More frequent meetings might be organised in case of need.

3.3. Network as a whole

The VBSCan network will connect all the stakeholders studying VBS at hadron colliders, creating the solid and multidisciplinary community necessary for future VBS measurements to succeed.
The scientific excellence of this proposal is demonstrated by the authoritative profile of the initial team of proponents, and by the expressed interest in joining the network by various institutions from COST ITC. The initial consortium has the critical mass, the expertise and the geographical distribution needed for addressing the ambitious challenges and objectives of the Action, and aims at becoming the worldwide reference community on the subject.
The capacity of the community will be maximised thanks to a thorough inclusiveness campaign. Careful training of ECI, a proper gender balance at all levels and maximal geographical openness will characterise the Action during the whole duration of the Action. Special care will be dedicated to the outreach of the VBSCan activities and of the results obtained, to maximise the visibility of the participating institutions and to reach the largest number of future participants to the Action. The concurrent development of all these lines will render VBSCan the needed resource to accomplish at best VBS measurements at hadron colliders, and to strengthen the European Union leading role in the field.