The case for a second extension of HESS operations beyond 2022

Considerations compiled for the H.E.S.S. Collaboration Board and the H.E.S.S. Steering Committee

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The evolution of H.E.S.S. since the decision to extend operations until 2022 continues to be very positive. Despite the difficulties imposed by the Covid-19 pandemic, the experiment operates very efficiently. Recent upgrades of the DAQ and the new camera for CT5 and changes in the organisation increased the reliability of operations. Further upgrades, such as the conversion of PMTs of the original CT5 camera for reuse in HESS1U cameras greatly lessen the risks resulting from aging hardware. The scientific productivity in amount and impact remains at the top level in the field of VHE astrophysics, and the performance of the array is expected to keep its leading role through 2025 – at least in the Southern hemisphere. There is a high demand for more observations and the responses to calls for proposals underline the very strong science case. At the same time, H.E.S.S. plays an important role in preparing the community for CTA and will continue to shape the CTA science programme. An extension of H.E.S.S. operations until 2025 is expected to be feasible at approximately the same annual cost as in recent years and will continue to be excellent value for money. While only the first year of the extension phase has been completed (significantly affected by the Covid-19 pandemic), the case for a second extension is made now to maximise the returns of such an extension.

Background:

The H.E.S.S. experiment was launched in 1999. After a five-year construction phase, the experiment took data for 15 years until 2019, which was the final date of operations under the original H.E.S.S. agreement. Based on strong support by the collaboration, the H.E.S.S. Steering Committee endorsed a three-year extension with corresponding agreements among H.E.S.S. parties (a revised MOU) and between the MPG, the Republic of Namibia and the owner of Farm Goellschau. This first extension covers the three year period October 2019 through September 2022, but allows for a subsequent extension. The first extension was granted with a number of specific recommendations and goals for H.E.S.S. operations which have been implemented successfully.

The status of the experiment and operations and forecasts through 2025:

The operational reliability of H.E.S.S. increased significantly. Thanks to improvements regarding hardware (DAQ upgrade, new CT5 camera), new organisation and measures (operations department, day shift crews) the amount of observations reaches a new record. 2020 will see the largest amount of data obtained in the history of H.E.S.S. (not counting moonlight for the ease of comparison) – despite the challenges of operating through the covid-19 induced lockdowns. Moonlight operations are now technically integrated (but could not be exploited fully in 2020 due to restrictions imposed to counter the spread of the corona-virus-pandemic) The full benefit of this new operations mode is expected to be exploitable in 2021. Future aims include a continued rise of efficiency, an extension of total observing time and further steps in automising operations while maintaining the excellent performance. Exploitation of new instrumental opportunities (sampling-mode observations, improvements of the sensitivities at the low- and high-energy end) and potential increase of moonlight time hold the promise for further qualitative and quantitative improvements of H.E.S.S. returns and will provide valuable experience for future CTA operations.
Measures to safeguard against risks due to aging hardware have been set up and will continue to maintain the high end-to-end efficiency. With the opportunity of using modified PMTs from the original CT5 camera as replacements for PMTs in the HESS1U cameras, no critical hardware component is predicted to fail before 2025, even if some auxiliary devices may be difficult to be kept in working order. Significant advancements in simulations, calibrations and with the three analysis chains (HAP, Model and gammapy) will facilitate cross-checks and help in assessing the

returns of new instrumental opportunities. Operations under moderate moonlight has been implemented and harmonised with classical dark time observations. Further steps will be explored in 2021. Contracts on operations (site, service contracts, access regulations) can be extended for a further three-year period. The very experienced staff is available for the same period. There are no legal or hardware obstacles to a further extension and the financial forecast suggests a stable requirement of overall support, with the future evolution of the exchange rate being the leading uncertainty in predicting financial needs budgeted in Euro.

The science strategy and future goals:

The observing program endorsed in 2019 and 2020 followed the science strategy proposed in 2018. Based on the first full annual cycle of observations of the first H.E.S.S. extension, the astrophysics working groups started discussions on the most attractive science program with a longer term vision for the remaining months of the first extension and a potential continuation beyond 2022. Most of the considerations that fed the 2018 strategy still apply, but recent advancements in the field suggest adjustments.

Time-domain studies and ToOs are likely to remain key scientific topics. Furthermore they are central elements in the strategic vision for the current H.E.S.S. and future CTA facilities, and the changing multiwavelength landscape.

GRBs are now established VHE sources, raising focused questions, arguing for new search strategies and benefitting from further triggers obtained by new satellites (GRB observations with SVOM, starting in 2022). GW-emitting BH- and NS-mergers are expected to be significantly more promising as the O4 run of the global GW-interferometer network will integrate the KAGRA detector and hence provide much more accurate positions for hundreds of triggers starting late 2022. Simultaneous observations of the entire gamma-ray band with HESS and the *Fermi*/LAT instrument shall be performed for source classes that have not been studied sufficiently in the (conservative) past efforts while both instruments remain operational. A strong focus on new source classes shall guide joint observations with new facilities in the X-ray and radio bands (e.g. NICER, MeerKAT). The searches for potential, rare gamma-ray transients triggered by high-energy neutrino and FRB detections shall be focused and continued.

Time-domain science goals include many questions that do not require triggers: Studies of pulsed VHE emission has already benefitted from the new CT5 camera. Gamma-ray binaries are a small but very interesting source class. New sources shall be investigated and secular variations in established objects are obvious targets. Joint observations of the SMBH in Sgr A* and M87 with HESS and the EHT array had a very promising start and shall be continued. It is also expected that long-term monitoring of few AGN prototypes will be a very valuable pathfinder for CTA.

The successes of past H.E.S.S. observations and discoveries obtained elsewhere also suggest a fresh look at steady sources. Key questions address to the highest energies in galactic and extragalactic sources, Cosmic Ray propagation and source populations. The results obtained with wide-field instruments (HAWC, LHASSO) suggests an adjustment of the focus of HESS studies of PeVatrons and requires a resourceful consideration of projects investigating extended sources.

The collaboration is also eager to explore new avenues, consolidating and extending previous efforts. This includes further observations to be combined with archival data to proceed with competitive studies of the Hubble constant and Dark Matter searches in galaxy clusters.

While all of these science goals can be pursued with the experiment in its current stage, individual projects may benefit from improvements and extensions of current science operations. The collaboration intends to explore and implement the promising options among, e.g., high zenith angle observations to improve sensitivity at the highest energies, exploitation of the sampling mode in order to increase the spectral range, an automised next-day-analysis to improve the observing strategy for transient sources.

The prime driver for the science strategy remains a strong track record of high-impact publications. The number of papers published remains high with no sign of a decay. The past 12 months demonstrate the continued ability of H.E.S.S. to attract the interest of the scientific community at large through publications in high-impact journals. The collaboration aims for a significant extension of the strong HESS publication record and is confident that the science programs described above will be an excellent basis.

Advancing methods during a further extension:

The key aim of an extension is continued operation of the current facility with its high overall performance to carry out the scientific observations described above. To the extent possible and subject to the addition of required personnel resources, an extension of HESS operations will allow to explore advancements in instrumentation and methods. Such efforts will also provide direct benefits to the H.E.S.S. programme (e.g. by improving the accuracy of calibrations or the versatility of the H.E.S.S. science operations).

H.E.S.S. and CTA:

CTA as a future infrastructure succeeding H.E.S.S. and other current-generation facilities is still awaiting a full budgetary complementation of available resources and needs for construction plus operation. A detailed and comprehensive plan for construction, supported by an approved and funded CTA ERIC may become available as early as 2021. Even in this case, however, it is very unlikely that the nascent CTA-South array will outperform H.E.S.S. before 2025. Conversely, H.E.S.S. will likely remain the only facility that will enable harvesting the promises of time-domain astrophysics mentioned above before 2025. An active VHE facility in this period when new opportunities emerge and any success of H.E.S.S. will undoubtedly benefit CTA significantly. The science results obtained with H.E.S.S. before 2025 will shape the key-science program of CTA which is expected to start after 2025 and will provide important clues for the key-science time of a re-scoped CTA array. The anticipated H.E.S.S. activities described above imply a continued pathfinder role of H.E.S.S. for CTA at an anticipated budget for operations with remains at a level of a few percent of the operational budget of CTA. H.E.S.S. will likely be an extremely cost-efficient precursor with a great potential of cost-improving future CTA operations.

Anticipated changes in data management:

Pooling the diversity of efforts in calibration, simulation and low-level data analysis is a vital goal of the current phase and a necessity for continued operations. The current duplication in calibration shall be terminated. Extending the ongoing efforts to these effects will benefit from an early decision about a further extension, as lead-times for changes are comparable to short-term appointments for required personnel.
An extension of operations would likely suggest that central elements in online and offline data management need upgrades. This is feasible with manpower involvement expected to complement continued operation. It would also be essential for long-term exploitation of H.E.S.S. data. Preparations to enable future access to archival H.E.S.S. data is technically not dependent on continued operations, but required personnel is much more likely to be recruitable for an ongoing experiment.

Anticipated benefits from continued operations:

The key expectation from a second extension of HESS operations are a very cost-efficient and reliable operation of this VHE facility with world-leading performance. New science opportunities emerging from H.E.S.S. results obtained until 2022 and anticipated new facilities will enable world-class science results. It will allow the full exploitation of recent investments and provide new science results with an excellent value for money. The facility is at its prime in terms of efficiency with further potential to explore additional automatisation. Conducting part of CTA-science will boost the science program eventually conducted by CTA, maintain the visibility of VHE gamma-ray results in the scientific community and maintain the attraction for the VHE gamma-ray astrophysics field for a new generation in a competitive environment.