**Contribution of CERN to the vacuum system of Einstein Telescope: a proposal**

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**Introduction**

Over the years, the Vacuum, Surfaces and Coatings group (TE-VSC) of the Technology (TE) department and the Material and Mechanical Engineering group (EN-MME) of the Engineering (EN) department have developed expertise in all domains of high, ultra-high and cryogenic vacuum for very large projects such as the Large Hadron Collider (LHC). This expertise includes the development and use of simulation and vacuum engineering tools, the design of vacuum systems and interfaces with room temperature and cryogenic environments, all coatings and chemistry diagnostics where needed, and the choice of material and manufacturing. The optimisation of performance-cost has always been a primary goal in any design and project.

Both groups have also actively collaborated on large international projects, contributed to reviews (MAX IV, KEK-B, ESRF, ESS, ITER are some examples), led work packages (MedAustron, MAX IV, FCC feasibility study) and often manufactured demonstrators, executing prototypes to be tested at CERN or worldwide, and providing specific technical industrialisation solutions. To enable this, the two CERN’s groups have consolidated and upgraded manufacturing techniques, vacuum testing, coating, assembly and material treatment infrastructures, some of which are unique in terms of performance and large size.

Since 2015, the two CERN’s groups pursued advanced R&D studies for very large vacuum systems, mainly driven by the Future Circular Collider feasibility study for both FCC-ee and FCC-hh options and exploiting synergies whenever possible with other projects with similar challenges and concerns. This has particularly been the case for the Einstein Telescope (ET) for which a Collaboration Agreement was signed in 2019 (KN4657/DG/Einstein Telescope) and a Letter of Intent with Cosmic Explorer (CE) signed one year later, in 2020.

The strength and experience of CERN vacuum experts in managing technical and large project collaborations make the option of coordinating all or part of the ET vacuum activities an interesting option for ET. For CERN, as previously mentioned, obvious synergies with core technical activities exist and therefore justify the interest in a larger collaboration with ET.

CERN may also be an interesting partner to unify and help the collaboration on a common platform, fostering a streamlined approach inside and outside the project, ensuring cohesion in one of the most challenging and costly systems of the ET project.

TE-VSC group could be the entity in charge of coordinating the vacuum activities. The proposed model would be similar to the one used for the EuroCirCol FCC feasibility study, more specifically for Special Technologies. In such a collaboration model, the coordination role consists of stimulating discussions and exchanges to build all needs including their technical descriptions. For example, sub-work packages, expected deliverables and milestones, as well as the identification of all potential contributors together with their competitive experiences and technical assets. An overview of the consolidated expected costs, spending profiles and schedule could be part of this coordination activity.

**Aims of the CERN’s contribution**

* In the spirit of the collaboration agreement KN4657/DG/EinsteinTelescope between CERN and the two Lead Institutes of the Einstein Telescope (INFN and Nikhef),
* Considering the mutual interest in vacuum technologies for large scientific instruments as reported above,

it is proposed that CERN drives the project activities for the vacuum systems of the ET arms (hereafter called by ET vacuum) in collaboration with other involved ET partners. This collaboration does not include the vacuum of the experimental towers nor the cryogenic traps at the pipe extremities).

CERN’s contribution has five objectives:

* The **coordination** of the contributions of CERN and all involved institutes to the development of the ET vacuum systems. To that end and in liaison with ET Project Office and US collaboration, CERN will take the responsibility to organise:
	+ Coordination meetings on average every two months to streamline the collaborations and contributions;
	+ An annual ET vacuum system meeting to address progresses and challenges of the ET vacuum system.
* The responsibility for the preparation and writing of the ‘**Technical Design Report**’ for the ET vacuum, including **cost estimations**.
* The involvement in the overall management of the ET project regarding the optimization of the interfaces between **vacuum systems and other infrastructure**, including integration in the tunnels.
* The design, manufacturing, assembling, and tests of a **prototype** of the selected vacuum system.
* The **contact** and sharing of information with **Cosmic Explorer** in the field of vacuum technology.

**Functional specifications**

The first step of the contribution would be the definition of the functional specifications, which comprises vacuum requirements and constraints with respect to infrastructures and services, in particular regarding the operational and maintenance costs.

To fulfil such objective, CERN would expect several inputs from the project about physics requirements, including:

* The upper limits of partial pressures.
* Requirements for pressure uniformities.
* Range of the diameter of the vacuum pipes.
* Roughness on the inner surfaces and diffused light requirements.
* Any threshold for light-dust interaction
* Requirement on surface contaminations.
* Alignment and pipe tolerances.

Inputs for services and integration would also be important; examples are:

* Vacuum chamber limitation in size and weight.
* Maximum heating power allowed in the tunnels.
* Maximum available electrical power available in the tunnel for bakeout.
* Maximum footprint available for vacuum pipe supports.
* Expected moisture level in the tunnel.
* Maximum allocated pumpdown time.
* Confirmation of expected lifetime (baseline is 50 years).

As several of these input are not yet settled, multiple iteration would be necessary.

**The baseline**

The baseline for the design of the vacuum system would be an upscale of the Virgo’s solution. This entails a vacuum system made of 304L stainless steel, 4-mm thick cold rolled sheet, ring reinforced, 15-m long modules, 1.2-m diameter. In the baseline, the number of modules is around 20 times higher than the one for Virgo. Hydrogen degassing is obtained by air firing at 400°C for 5 days. The in-situ baking is performed at 150°C for one week. The pumping is based on ion and getter pumps.

The baseline would need a few adjustments required by the different lenght and environment of operation in ET. Updated and detailed cost analysis would be prepared.

**Alternative solutions**

In parallel, other solutions would be investigated only with the well-defined objective of reducing the overall costs with respect to the baseline, while preserving the same performance. In these investigations, CERN would coordinate the effort of all institutes and industries ensuring a coherent development and sharing of advancements among the collaborators.

Alternative solutions would be developed in terms of conceptual design, feedback from industry, feasibility at ET scale, optimisation of the interfaces and integration, support optimisation and cost estimation. Examples are:

* Corrugated stainless steel pipes.
* Use of less expensive materials, including mild steels, martensitic and ferritic stainless steels.
* Thin walls reinforced by resins.
* Use of coatings to avoid bakeout.

The study of alternative UHV pumps would be included in this contribution.

**Final choice of the vacuum system technology**

The choice of the vacuum system would be made by the project directorate two years after the beginning of this collaboration on the basis of the design, tests and cost analysis obtained at that time.

**Manufacturing and prototyping**

CERN would manufacture, install and test prototypes of the selected solution to be evaluated in terms of performance and cost. The main objective would be the test of the selected design at the ET scale, except for the length. The prototypes would be installed in CERN’s premises.

This include:

* Supply by the EU industry
* Welding of pumping ports and extremity flanges.
* Real scale cleaning and its assessment by surface analysis.
* Assessment of the proposed degassing treatments.
* Test of tolerances, support stability and adjustment.
* Installation of the selected pumping system.
* Bakeout, leak tightness and ultimate pressure measurements.

**Technical design report (TDR)**

The TDR would be the main outcome of the CERN’s contribution, including manufacturing, post-production treatments, installation, and commissioning procedures. The interfaces with the tunnel infrastructures and services would be also included in the TDR. It would contain the manufacturing drawings necessary for the prototypes and the integration with the other vacuum systems (towers and cryogenic traps).

**Contacts with Cosmic Explorer**

CERN would ensure the link with the Cosmic Explorer vacuum technology community. Experimental data, results, and progress would be openly shared in regular meetings. Such contacts would have the positive effect of cross-fertilisation and peer review between the two communities.

**Regular reporting**

CERN would report to the ET directors by means of regular meetings and monthly written reporting and will have the responsibility to organise coordination meetings on average every two months to streamline the collaborations and contributions, and an annual ET vacuum system meeting to address progresses and challenges of the ET vacuum system.

**Planning**

|  |  |  |  |
| --- | --- | --- | --- |
|  | First year | Second year | Third year |
|  | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| Functional specifications |   |   |   |   |   |   |   |   |   |   |   |   |
| Roles and agreement with Institutes |   |   |   |   |   |   |   |   |   |   |   |   |
| Optimisation of baseline, including cost analysis |   |   |   |   |   |   |   |   |   |   |   |   |
| Definition of alternative solutions |   |   |   |   |   |   |   |   |   |   |   |   |
| Cost & performance of alternative solutions |   |   |   |   |   |   |   |   |   |   |   |   |
| Optimisation of interfaces with services/infrastructures |   |   |   |   |   |   |   |   |   |   |   |   |
| Decision about vacuum system final solution |   |   |   |   |   |   |   |   |   |   |   |   |
| Prototyping of the selected solutions |   |   |   |   |   |   |   |   |   |   |   |   |
| Technical design report (ET vacuum system) |   |   |   |   |   |   |   |   |   |   |   |   |

**Required resources**

|  |  |  |
| --- | --- | --- |
| **[person-year]** | **CERN** | **ET** |
| Supervision and collaboration coordination | 0.6 |   |
| Manufacturing and cost analysis | 0.6 | 1.5 |
| Metallurgy, cleaning, post-production, and assembly | 0.9 | 1.5 |
| Mechanical engineering | 0.9 | 1.5 |
| Vacuum technology and technical support | 3 | 1.5 |
| **Total of personnel [person-years]** | **6** | **6** |
|   |   |   |
| **Material costs [kCHF]** | **100** | **100** |

Considering that these developments are of common interest, this collaboration foresee a similar level of resources on CERN and ET side.

* CERN manpower contribution would be based on staff members, which total contribution, will amount to a level of two persons per year during three years, so six person-year in total. The cost of Staff is meant to be shared between CERN and ET project.
* ET would support an additional two CERN fellow hired through the AFC selection committee, or equivalent administrative bodies for three years, so six person-year in total.

It is estimated that material and services will cost around 200 kCHF shared between CERN and ET. To be noted that CERN do not charge any overhead to this collaboration.

The proposed cost sharing for the three years of the agreement is shown in the following table.

|  |  |  |
| --- | --- | --- |
|  | **CERN [kCHF]** | **ET [kCHF]** |
| CERN staff\* [G5 + G6] | 433 | 433 |
| ET contribution to finance CERN fellows | / | 600 |
| Material | 100 | 100 |
| **Total** | **533** | **1133** |

*\*2 FTE.y of Technical Engineer (CERN grade 5) and 2 FTE.y of Engineer/Physicist (CERN grade 6) for 3 years*

The cost of overhead, standard services, and occupation of premises at CERN is not charged to ET. It is considered as part of CERN contribution to the collaboration.

JMJ & PCh

