Project information

Project full title	European network for developing new horizons for RIs
Project acronym	EURIZON
Grant agreement no.	871072
Instrument	Research and Innovation Action (RIA)
Duration	01/02/2020 – 31/01/2024
Website	https://www. eurizon-project.eu

Deliverable information

Deliverable no.	D2.2 (D7)
Deliverable title	STS system integration procedure engineered
Deliverable responsible	FAIR GMBH
Related Work-Package/Task	WP2; Task 2.1
Type (e.g. Report; other)	Report
Author(s)	J. Heuser (GSI-FAIR), for the WP2.1 participants
Dissemination level	Public
Document Version	1.1
Date	25.01.2024
Download page	https://www.eurizon-project.eu/results/deliverables/

Document information

Version no.	**Date**	**Author(s)**	**Comment**
v1.1	25.01.2024	J. Heuser et al.	approved by WP2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072.

Contents

1. WP2.1 final delivery D2.2:
The CBM Silicon Tracking System and its integration procedure engineered

In this report we summarize the final delivery of Work Package 2.1, revised for the second part of the project. The works carried out address the preparation of the Silicon Tracking System (STS), the central particle detector of the *Compressed Baryonic Matter* (CBM) experiment under realization at the FAIR accelerator facility, Darmstadt, Germany. While in the first part of the project the development of STS components was achieved and reported in delivery report D2.1, in particular the assembly and test of detector modules and ladders out of which the STS system will be put together, the engineering of their integration into a system is the topic of the second and final delivery report D2.2.

The dipole magnet plays an important role for the detector integration because the STS detector will be installed into the field gap between its coils. There, it measures the trajectories of the charged particles created in the beam-target interactions, and determines the particles' momenta from their bend in the magnetic field. Therefore, the interplay between available space in the magnet, physics aperture, position in the magnetic field and the STS detector design requires a perfect match for a successful physics program. But as a consequence of the Russian war on Ukraine, the CBM superconductive dipole magnet, that was under construction at the Budker Institute of Nuclear Physics as Russian in-kind contribution to FAIR, became unavailable to the CBM experiment. The CBM Collaboration was forced to explore other delivery options. Finally, permission was obtained for this and a tender conducted. A new magnet will now be provided through Bilfinger Noell GmbH, Germany.

The design effort required for the new magnet also opened the possibility to improve aspects of the STS detector engineering, that was already partly achieved. The new situation was taken into account in the works reported here. The STS design was made more modular and flexible for its installation and a future repair or upgrade scenario. It was separated into an upstream part with three tracking stations as independent insert into the detector mainframe, while keeping the downstream part with five tracking stations in place. The revised detector still fits into the confined space of the magnet gap – which in turn had to become slightly higher.

The final engineering of the STS detector is further described in the next section. The design is fully detailed. This allows proceeding with the series detector module assembly as the assembly sequence has been fixed. Also, the procurement of mechanical components can be conducted now, starting with the bottom and top plates of the STS mainframe. They will be made from carbon sandwich material for ultimate sturdiness and form stability, allowing for the required precision position measurements of the STS silicon sensors of the order of 10 micro meter.

2. Re-design of the STS mechanical structure and system integration procedure

2.1 The initial “monolithic” detector

The design of the Silicon Tracking System, conceived years ago and documented in the STS Technical Design Report [1], comprised eight tracking stations built from 876 silicon detector modules on 106 detector ladders, which are in installed into one detector mainframe which in turn fully filled the tight space constraints of the dipole magnet’s gap. This design was entirely optimized for the physics to be carried out at SIS100 and SIS300, and here in particular at their upper beam energy ranges. This design was of a “monolithic” construction, i.e., once the detector was assembled, no easy access to its components was given, with the consequence that maintenance, replacement, or potential future upgrades were only possible by full disassembly. The initial detector system as outlined here is depicted in Figure 1.

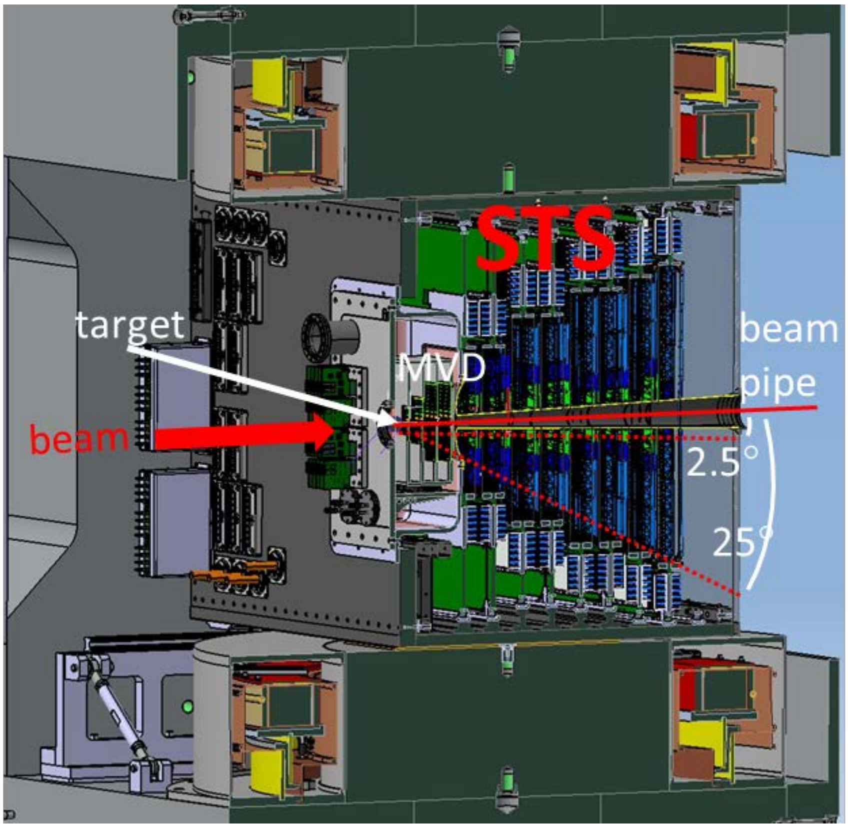

Figure 1: The “monolithic” Silicon Tracking System in the dipole magnet. Shown is a cross-cut view of the magnet with its coils and the mainframe of the STS in its gap with the eight tracking stations filling up the space in it. Further components are the target vacuum box with an additional high-precision silicon vertex detector (MVD), and the passive component “beam pipe” which guides the non-interacting beam particles in vacuum through the experiment. Also shown is the physics aperture for charged-particle tracking in the polar angular range between 2.5 and 25 degrees.

This project has received funding from the European Union‘s Horizon 2020 research and innovation programme under grant agreement No. 871072.

2.2 The new “modular” detector

The new “modular” concept keeps all internal developments of the detector building blocks. However, their mechanical arrangement has been modified such that the mechanical units U00 – U03, forming the upstream three tracking stations, are mounted in a separate sub-frame that itself inserts into the mainframe of the downstream units U04 – U07, realizing further five tracking stations. The transition from the monolithic to the modular design is shown in Figure 2.

The sub-systems, by themselves, are two completely independent systems and can be separately assembled with all their services. Those are layered such that the upstream sub-frame is insertable into the outer mainframe – like a module into a crate. The internal designs are kept; unit/station layout and all detector and module designs remain the same. Outer frames and cabling have been adapted. Access to the services is from the upstream side. This concept requires an additional rail system in the overall mainframe. Therefore, the overall space requirements of the STS detector changed: height +3 cm, width +30 cm. This is expressed in the specifications of the new magnet. The gap dimensions need to fulfill the dimensions 2000 mm length, 3300 mm width and 1470 mm height.

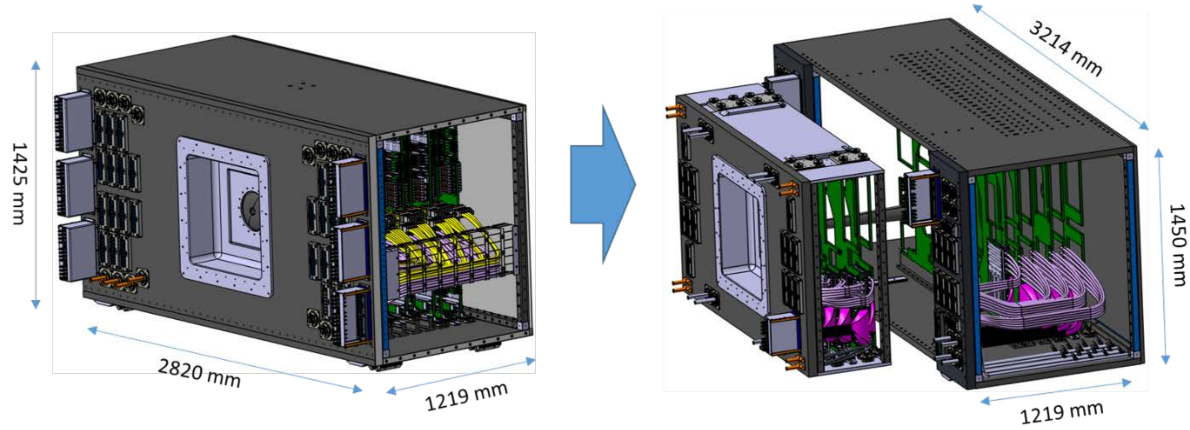

Figure 2: The monolithic STS design (left) re-designed into a modular system (right) made from two blocks of tracking stations that can be assembled independently from another. The upstream smaller block inserts into the outer mainframe. The overall dimensions of the STS system increase in width and height.

This project has received funding from the European Union‘s Horizon 2020 research and innovation programme under grant agreement No. 871072.

2.3 Performance studies of the new detector design

The performance of the new detector design has been verified in physics performance simulations. Using the *CbmRoot* software framework, the geometry of the detector was encoded and the new magnet, with an enlarged gap to fit the detector, was applied with field maps prepared by the CBM Collaboration. The side view of the magnet yoke and the magnetic field lines as used in the simulations are shown in Figure 3.

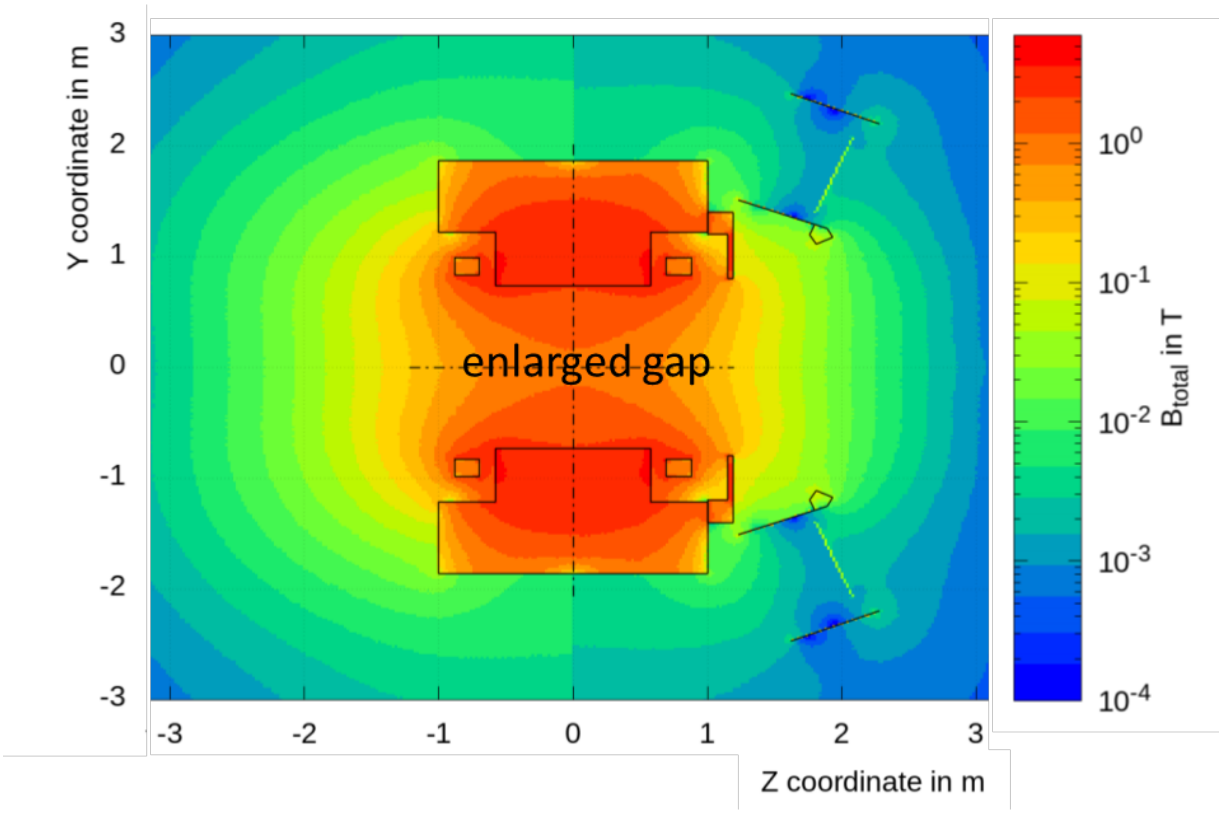

Figure 3: Visualization of the CBM dipole magnet's iron yoke in projection along the beam axis, with the gap between the magnet coils shown according to the enlarged dimensions. The magnetic field produced by the coils and the return flux through the yoke is shown in the color encoding.

The simulation geometry of the new detector is visualized in Figure 4. All relevant components, from the active detector modules and ladders, to a representation of the read-out electronics, and mechanical mounts like the outer and sub-frames and the vacuum beam pipe, have been encoded.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072.

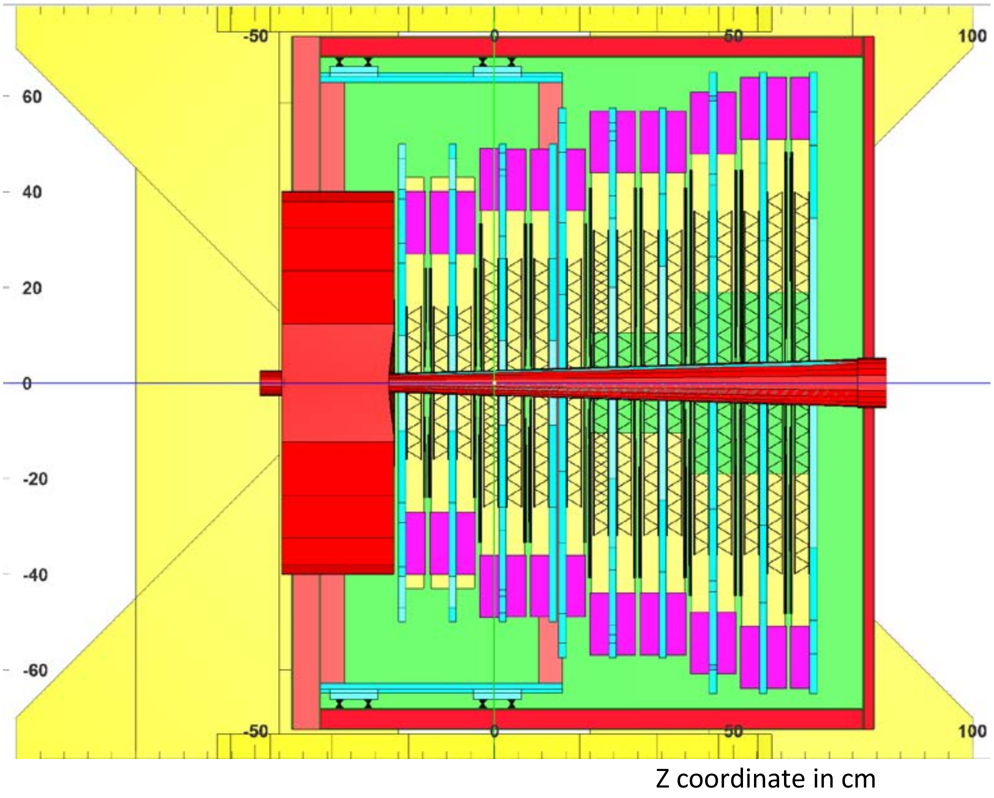

Figure 4: Simulation geometry of the revised STS detector. It focuses on representing the main components in a simplified but sufficiently accurate fashion. The outer mainframe is shown in this cut-through view in red color. Inside, the upstream sub-frame is visible, mounted on support rails. The vacuum beam pipe of the STS section passes through the entire detector, attaching to the target vacuum box on the left to the downstream wall of the detector. The detector ladder structures with their carbon fiber frames are shown in the center (black), and the electronics blocks at the perimeter of the physics aperture (pink). In the background of this view, the magnet iron is shown in yellow.

The simulation was carried out in the Virtual Monte Carlo software framework of *CbmRoot* by transporting particles from *UrQmd*-generated beam-target interactions through the simulated detector. The particles interacted with the simulated detector structures and particle trajectories were reconstructed from the virtual representation of physical detector data. Information on the detector performance was obtained by analyzing those particle tracks in the bend of the dipole magnetic field. The results show that physics performance remains high. Some of the most characteristic diagnostic information is shown in the plots of Figure 5. The track reconstruction efficiencies at two magnetic field strengths, and the momentum resolution show essentially no difference of the re-designed detector when compared with the original conception.

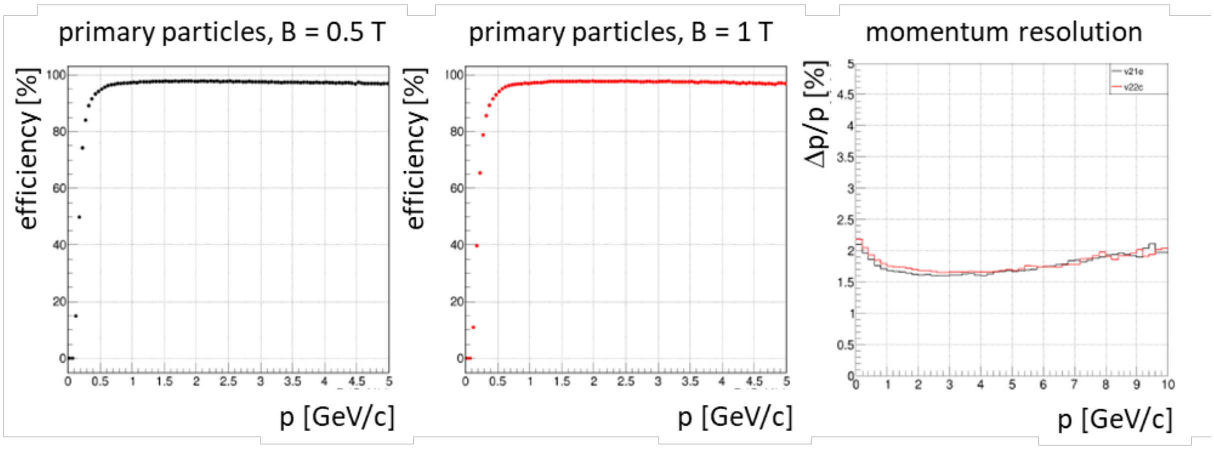

Figure 5: Performance of the new detector design in comparison with the previous, original STS design. Three particular performance figures are shown here. The left and middle plot show the overall particle reconstruction efficiency, at two magnetic field strengths, as a function of the particle momentum. In both magnetic fields, a low-field and a high-field operation, the detector reaches high performance with above 97% particle reconstruction efficiency for momenta exceeding 1 GeV/c. The curves are single lines – one cannot distinguish the old and the new detector concept; the performance remains unchanged and high. In the plot on the right, which shows the relative momentum resolution of the particles as function of their momenta, shows only very slight difference between the two detector geometries. The performance remains essentially unchanged, and as expected. The difference is due to an extended inner detector length of about 4 cm, necessary for the insertion of an extra mechanical frame.

2.4 Full detailing of the re-designed detector, production of its parts

With the confirmation of the validity of the re-designed detector design obtained through the physics simulations, the full engineering effort could be spent on the complete detailing of all components. The CAD design is shown in Figure 6 for the fully integrated detector. Two situations are illustrated, the combined up- and downstream parts, and the upstream part taken out of the outer frame. With this work status achieved, the STS project team can now proceed with the preparation of the production of the detector mechanical parts, beginning with the top and bottom plate of the outer mainframe. Integral part of the STS detector is also its section of the vacuum beam pipe. It fits the new detector design. A prototype of the pipe has been manufactured from carbon fiber and is shown in Figure 7.

The series assembly of detector modules and their integration onto detector ladders has started. Components for production readiness demonstration have been completed – Milestone M7 of this Work Task WP2.1, achieved by M48. The work leading to it has been published in [4]. The work is very specific and thus conducted in assembly laboratories of GSI and in cooperation with KIT within the CBM Collaboration. The sequence of the module and ladder production and their further integration into the detector system is now fully defined by the engineering design of the STS and the topological constraints of its two sub-assemblies. Production started with the most upstream modules and ladders of the 5-station outer frame structure.

The installation of the detector into the magnet has also been engineered. A rail system in the magnet gap below the bottom coil will receive the detector with matching gliders mounted to its bottom support plate. An auxiliar support table will be used to move the STS detector into position in the magnet. Two depictions of the detector in magnet are shown in Figure 8 to complete this deliverable report.

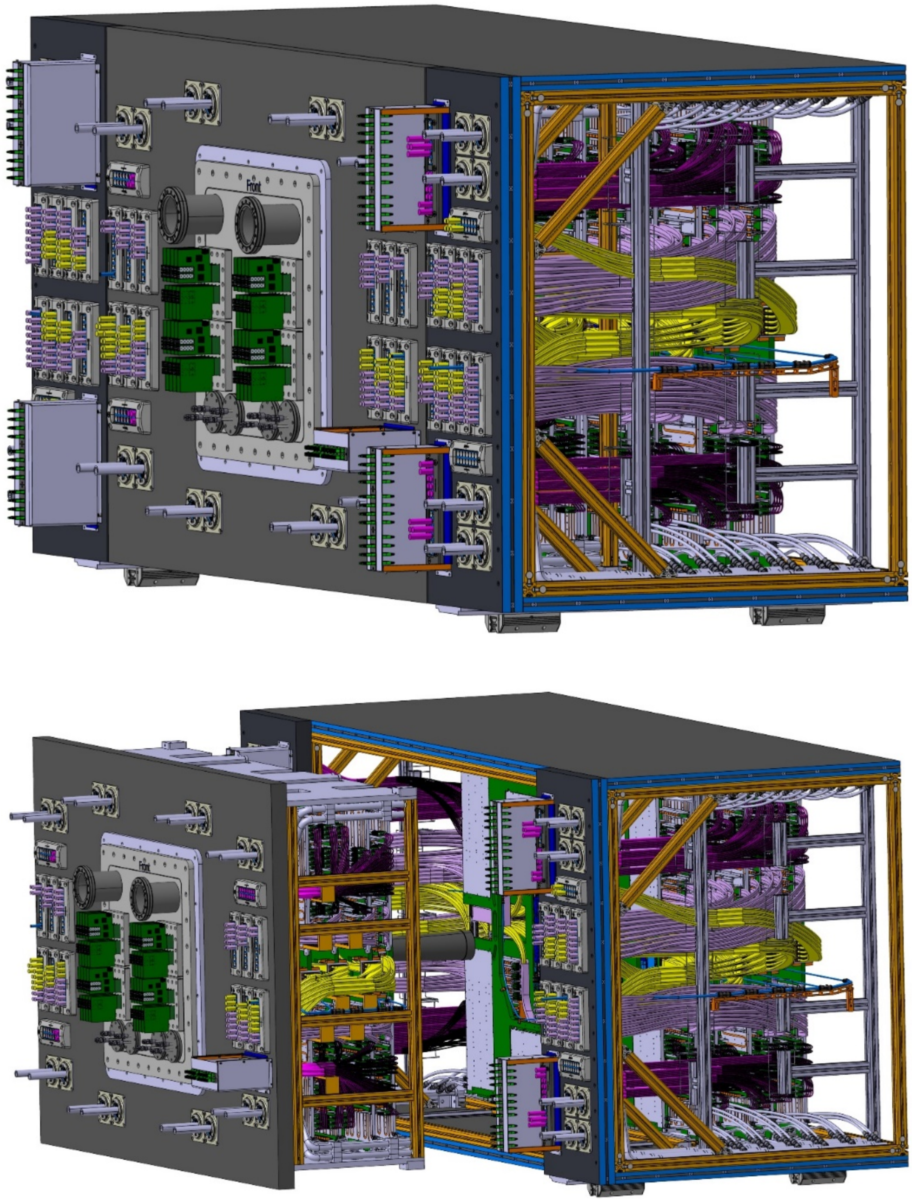

Figure 6: Views of the fully detailed engineering designs of the re-designed STS detector. The top panel shows the detector in integration configuration, while the pottom panel depicts the situation with the sub-frame taken out of the outer frame. In both cases, the side and back walls have been removed from the CAD view to allow for transparency to view the internal structures of detector structures, mechanics and service infrastructure as cabling and piping. All connectivity to the detector is accessible from the upstream wall (left).

Figure 7: Prototype of the STS section of the CBM vacuum beam pipe. It was produced according to the dimensions of the re-designed STS and manufactured in industry.

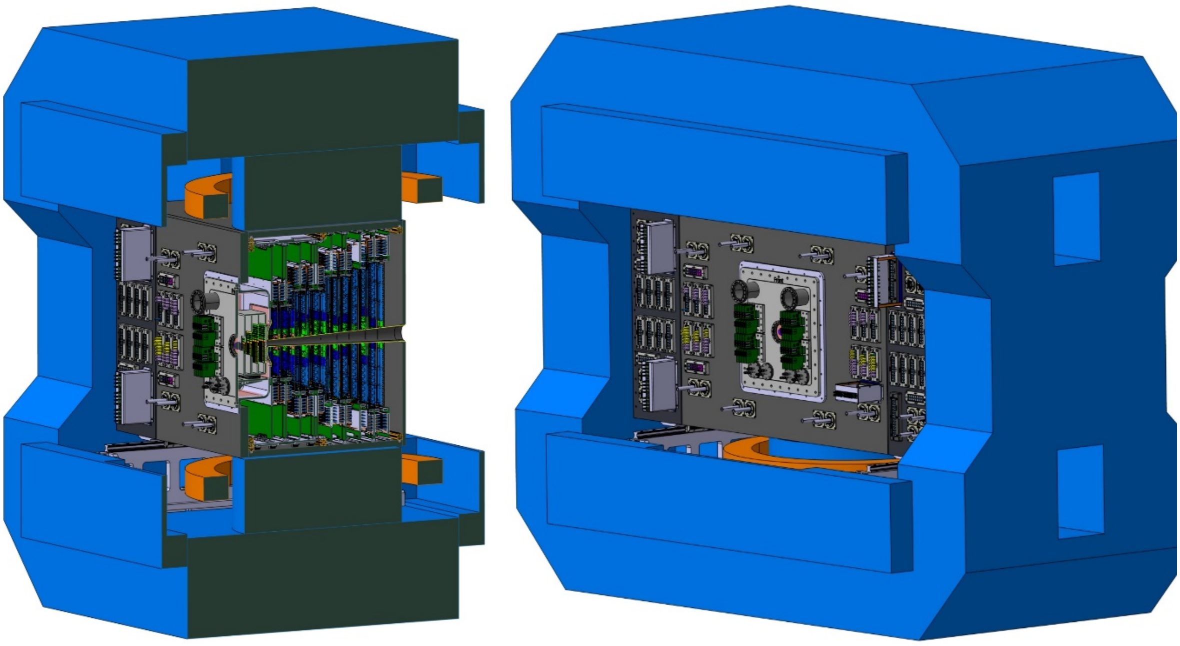

Figure 8: Perspective views of the re-designed STS detector in the new CBM superconducting dipole magnet.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072.

Acknowledgements

The works within the STS project of the CBM Collaboration are carried out by the following teams. In particular the successful interplay of the different work tasks is acknowledged.

- GSI-FAIR (Germany) *+
- EKUT Eberhard Karls Universität Tübingen (Germany) *++
- GU Goethe Universität (Germany)
- KIT (Germany)
- AGH (Poland)
- JU (Poland)
- WUT (Poland)
- KINR (Ukraine)
- KEK (Japan) - associate CBM member

* WP2.1 participant on the CBM-STS engineering, simulation studies and assembly
\+ Technical coordination
\++ Project leadership

References

[1] J. M. Heuser et al., eds., *Technical Design Report for the CBM Silicon Tracking System (STS)*, GSI Report 2013-4 (2013)

[2] M. Shiroya et al., *New concept for the Silicon Tracking System: STS-3+5, simulation geometry*, CBM Progress Report 2022 (2023), pp. 19-22, DOI: 10.15120/GSI-2023-00384

[3] O. Vasylyev et al., *Modular redesign of the STS detector,* CBM Progress Report 2022 (2023), p. 23, DOI: 10.15120/GSI-2023-00384

[4] A. Rodríguez Rodríguez et al., *Functional characterization of modules for the Silicon Tracking System of the CBM experiment,* NIM A 1058, January 2024, 168813, https://doi.org/10.1016/j.nima.2023.168813