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CBM Collaboration

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Report on the production of prototype STS ladders

CBM-STS team

GSI, Darmstadt, Germany and JINR-VBLHEP, Dubna, Russia

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Abstract

We summarize the achievements on the preparation of prototype STS detector ladders for application in the CBM experiment at FAIR and in the BM@N experiment at Nuclotron.

The work has been done with support from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 654166 (Project CREMLIN) [1]. This note serves as deliverable 1 of the project's work package 3 "Science cooperation with the NICA collider facility in the field of ion beams and heavy ion physics".

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1 Introduction

The silicon tracking detector systems STS of the experiments *CBM at FAIR* [2] and *BM@N at Nuclotron* [3] will be built from nearly structure-identical building blocks, the so called detector modules (functional units of double-sided silicon microstrip sensors, ultra-thin signal microcables and front-end electronics) which are mounted onto carbon fiber frames, forming detector ladders. These detector ladders can be butted side by side in order to form a tracking station, one of several in the STS detectors.

The two silicon tracking detector systems for the heavy-ion physics experiments CBM at FAIR and BM@N at Nuclotron/NICA are depicted in Fig. 1. The CBM Silicon Tracking System is the larger one, comprising 8 tracking stations that are installed between 0.3 and 1.0 m downstream of the target point inside the CBM dipole magnet with 1.44 m vertical gap between its magnetic poles. The CBM-STS tracking stations 1-4 are comprised of 400 detector modules, i.e. units of silicon microstrip sensors, microcables and front-end electronics, mounted onto 46 carbon fiber support structures (ladders). The tracking stations 5-8 will comprise 496 modules on 60 ladders. The integration work will include the mounting of ladders onto 18 mechanical frames. Those half-units will be installed in a thermally insulating mainframe around the vacuum beam pipe and completed with on-detector data-combining electronics and power distribution boards, electrical and optical cabling, cooling infrastructure for electronics and sensors, as well as their interfaces to external supplies and services. Very similarly, the BM@N Silicon Tracking System is built from four tracking stations with a total of 252 modules mounted on 40 ladders. The ladders comprise the same module components and passive parts as the CBM-STS. The overall mechanical layout is somewhat different and its data acquisition and controls interfaces specific to the BM@N experiment. The detector system will be installed into the wide-aperture BM@N magnet of about 50 cm vertical gap between 20 and 80 cm downstream of the target.

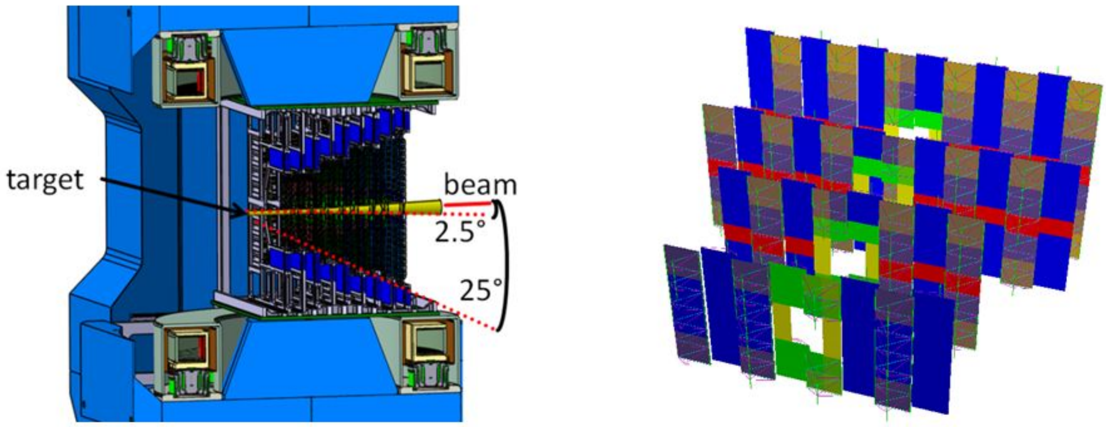

Figure 1: CBM Silicon Tracking System with 8 stations in the dipole magnet (cut-through view, left). Ladders arranged in 4 stations for the BM@N Silicon Tracking System (right).

The detector ladders are described in [4] from which is quoted here. “The modules are mounted onto lightweight space frames with end supports, the “ladders”. A ladder comprises two times five modules. A general view of a ladder and the arrangement of ladders into tracking stationsis shown in Fig. 2.The concept of the carbon-fiber space frames was developed for the barrel geometry of the Inner Tracking System of the ALICE experiment and has been adapted to the use case in the CBM-STS. As the contribution of the mechanical structure to the material budget is small comparedto the thickness of the sensors, the ladder structure was inherited with minor modifications only. It consists of three carbon beams arranged in a triangular cross section supported by an arrangment of carbon side pieces. Originally developed for the ALICE experiment, the fabrication of the ladders is based on a one-cycle polymerization process at 125 °C in a metallic mold.” Such frames have been assembled and stored for use in the BM@N experiment at JINR. Alternatively, a semi-industrial process has been developed by the German team for use in the CBM experiment. Here, hollow carbon fiber tubes are arranged in a triangular cross section on a winding tool. Carbon fibers are then spun around to finally yield the ladder structure.

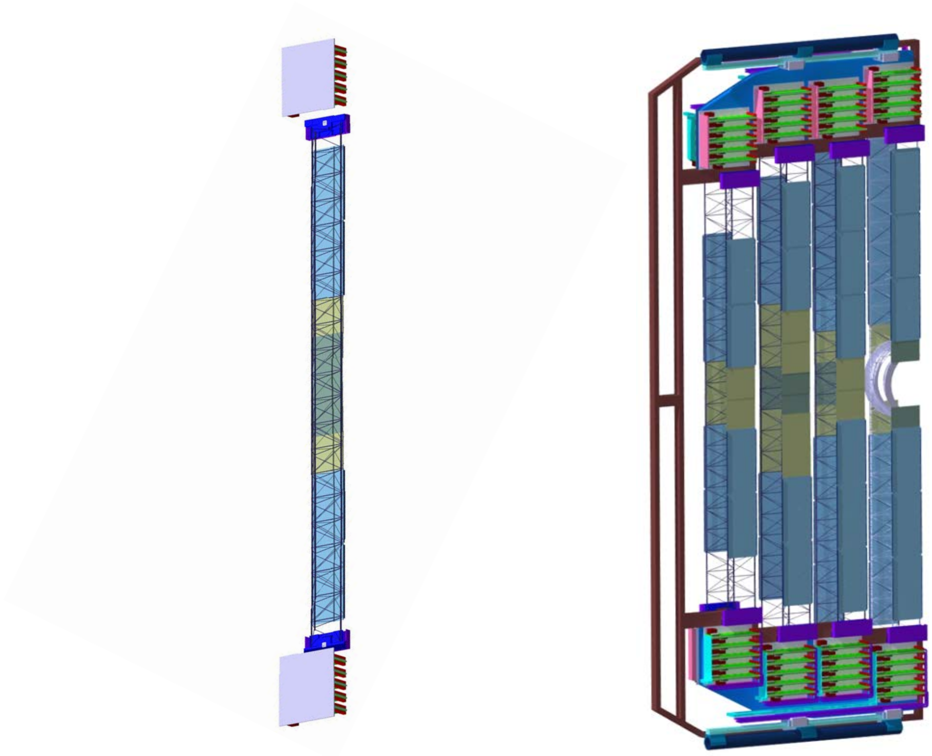

Figure 2: General view of a detector ladder with electronics blocks at its ends (left). Arrangement of ladders to form a half-station with overlapping sensors (right).

The ladders are assembled using dedicated sets of tools, aming at safe handling the delicate double-sided modules and at achieving repeatable mechanical precision in the three-dimensional module positioning on the ladder with less than 100 μm tolerance. That margin has been determined sufficent for the in-experiment application of software procedures to establish a refinement of the sensor position alignment with particle hits and tracks [5].
Two different ladder assembly approaches are being followed up at JINR and at GSI. They are described in this report in the section 2 (based on report [6]) and section 3 (based on report [7]). The achievements using the GSI procedure for protptype ladder assembly on the pre-curser experiment *mCBM* [8] at GSI-SIS18 in 2018 and 2019 is summarised in the last section 4.

2 Ladder assembly at JINR

At JINR, the assembly procedure involves a device that is equipped with 10 precision tables. They receive detector modules with sensors that have already been equipped with four “L-legs”, several milli meters sized glass fiber angles attaching to the silicon sensors with the short arm and to the carbon structure with the long arm. Up to 10 modules are aligned onto those tables and then later the carbon fiber ladder support is lowered onto the modules and the L-legs are glued to the carbon beams.

The accurate positioning of modules with two daisy chained sensors of size 6.2 x 6.2 cm^2, a particular technical alternative to a module with one monolithic 6.2 x 12.4 cm^2 sensor, on a ladder is the key challenge addressed to the ladder assembly device since the required accuracy of positioning of strips of the chained sensors is of the order of 10 μm in lateral Y direction across the ladder.

JINR’s industry partner, PLANAR, Minsk, Belarus, was contracted to do design and manufacture the basic elements and optical system for control of the assembly with basic elements (Figs. 3 and 4) that are already partly manufactured.

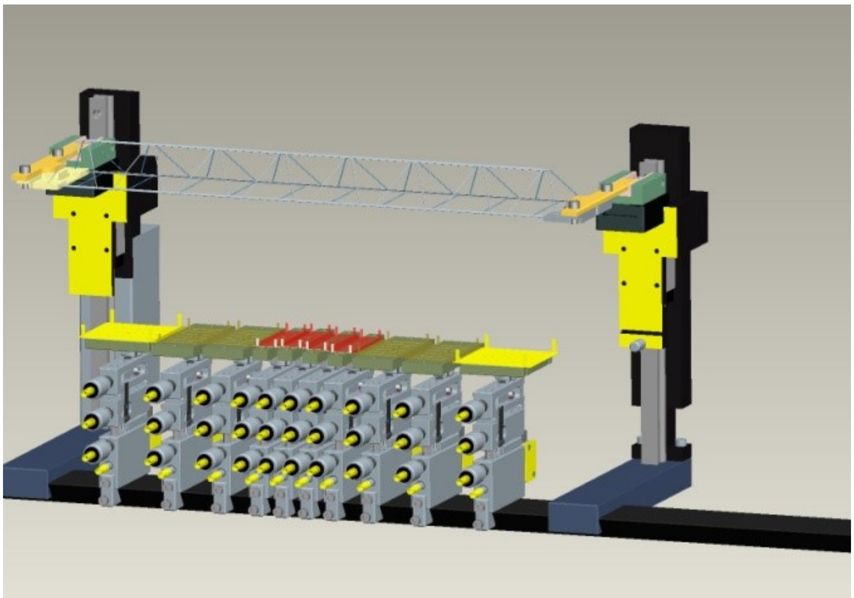

Figure 3: The design of the device key elements: individual vacuum chucks for each sensor of the ladder; CF support truss is ready for positioning “in-between” modules L-legs for gluing; the control optical system is not-shown for simplification.

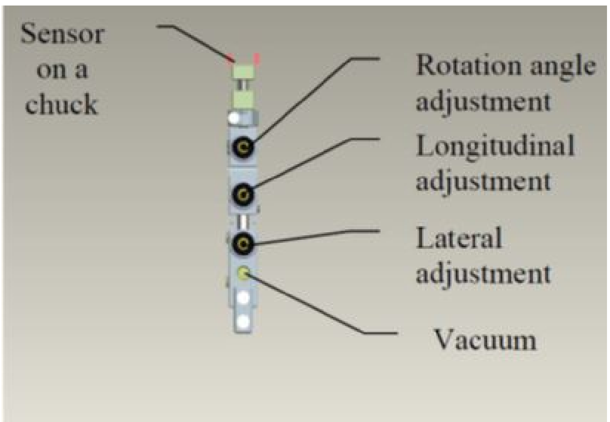

Figure 4: The design of the individual sensor vacuum chuck manipulator used for finite adjustment of sensors prior to gluing to carbon fiber truss.

After installing all modules in the working position, the individual sensors' fiducials are aligned along the central line of the ladder to allow the carbon fiber truss to be lowered from above to glue the L-legs of the modules to the truss to fix all sensors on the ladder. The expected accuracy of sensor positioning in Y-direction within $\pm 12\ \mu$ m is still to be tested.

3 Ladder assembly at GSI

At GSI, the assembly procedure uses tools that are more simple by themselves but are based on accurate machining. The real positions of the sensors will be derived from an optical survey after assembly. The procedure first installs the carbon fiber ladder into the tool, attaches the end plates and the L-legs, and then – in a serial manner – grabs every detector module with a precision transfer tool and places it on top of the carbon ladder using for subsequent glueing.

The positioning requirement for the sensors is 100 μm. To reach this precision the fixture has to be kept at a constant temperature in a controlled environment. After assembly the position of the sensors will be measured.

For the metrology of the sensors on the ladder a three axis measurement instrument has been recommissioned (Fig. 5 left). It can measure objects up to 1100 x 800 x 170 mm. The maximal deviation of this device after applying corrections has been measured to be less than ± 10 μm. The setup is equipped with a camera; the procedures developed for the quality assurance of sensors have been adapted to the metrology of ladders.

A concept tool has been designed and produced (Fig. 5 right). With the tool two 6 x 6 cm^2 sensors can be mounted on a CF-ladder. The tool is used for gluing the L-legs to the Ladder. The L-legs are fixed and moved for gluing guided by a rail system to the carbon fiber structure. The sensor is positioned with a vacuum holder. The vacuum holder itself is positioned to the fixture with dowel pins.

To study the mounting precision a ladder has been assembled with two non-functional sensors (Fig. 6). The precision of the mounting has been measured with the camera system to be within $\pm$ 40 μm. The concept of the ladder assembly has been successfully tested by assembling a ladder with one mechanical dummy module (Fig. 7 left).

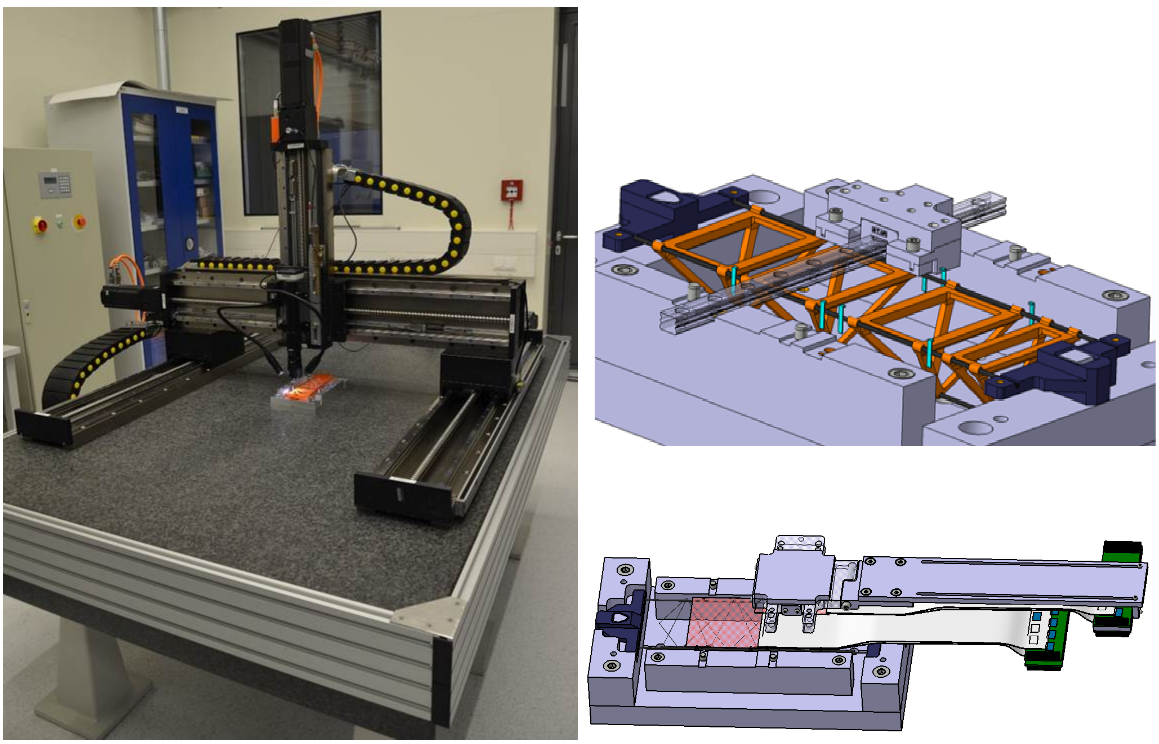

Figure 5: Movable camera system for inspecting assembled ladders (left); Positioning tool to holding two L-legs and a module during assembly (right).

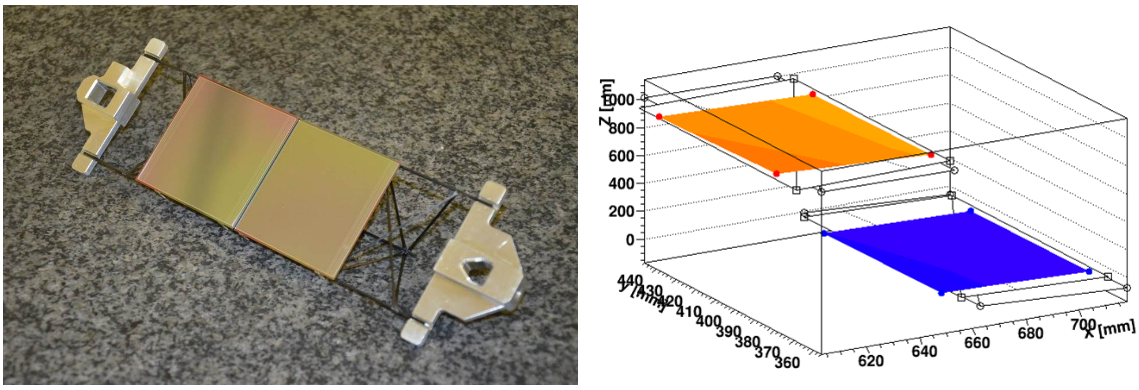

Figure 6: Two sensors glued onto a carbon fiber structure (left); Metrology of the mounted sensors (right).

4 Prototype ladders for the precursor experiment mCBM

An improved large scale prototype tool (Fig. 7 right) has been designed for the assembly of ladders for the mSTS detector in the demonstrator experiment “miniCBM”, currently under set-up at GSI-SIS18 for operation in 2018 and 2019. Equipped with functional sensors, the handling and gluing of the sensors will be tested to ensure that it has no influence of the performance of the detector. Using this fixture, a half-ladder has been populated with 5 dummy modules, shown in Fig. 8. Optical metrology confirmed all sensors being mounted meeting the geometrical tolerance requirement. A transfer tool to take the ladder out of the mounting fixture has been prototyped to proof the concept of transfering it to the detector's C-frame. This was confirmed with a mechanical demonstrator of the larges STS C-frame for station 7, depicted in Fig. 9.

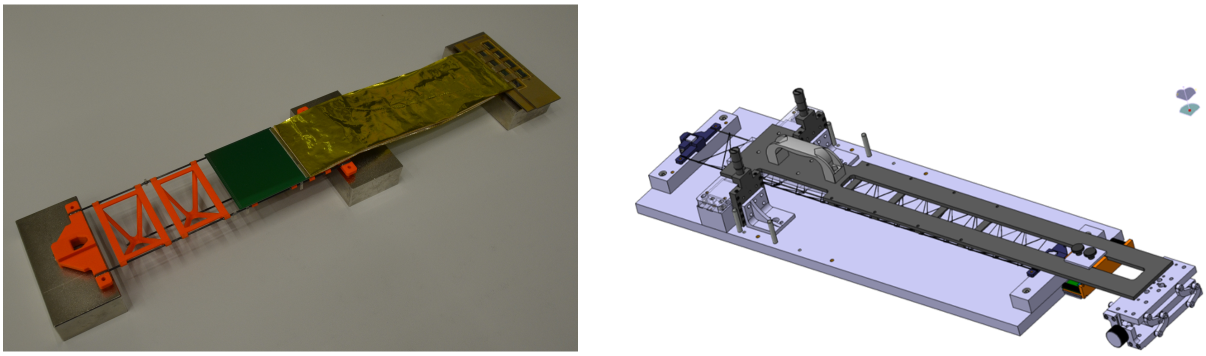

Figure 7: A dummy module mounted on a dummy 3d-printed ladder for the purpose of demonstration (left); the assembly tool for the mSTS ladders designed (right).

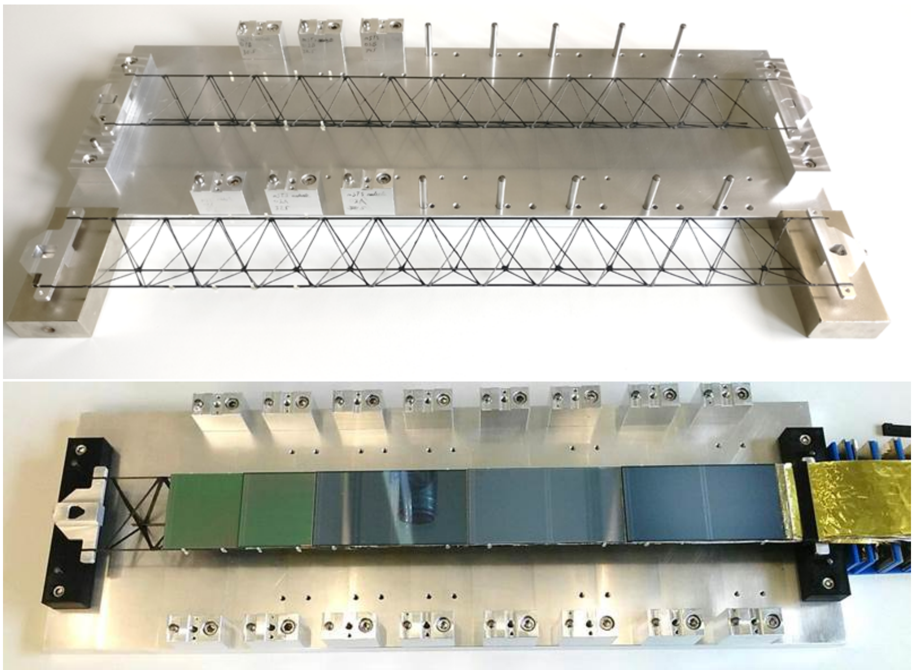

Figure 8: Carbon fiber ladders for mSTS in mCBM equipped with mounting end-plates and L-legs in the assembly fixture and a storage cradle (top); ladder assembly test with 5 mockup modules in the assembly fixture (bottom).

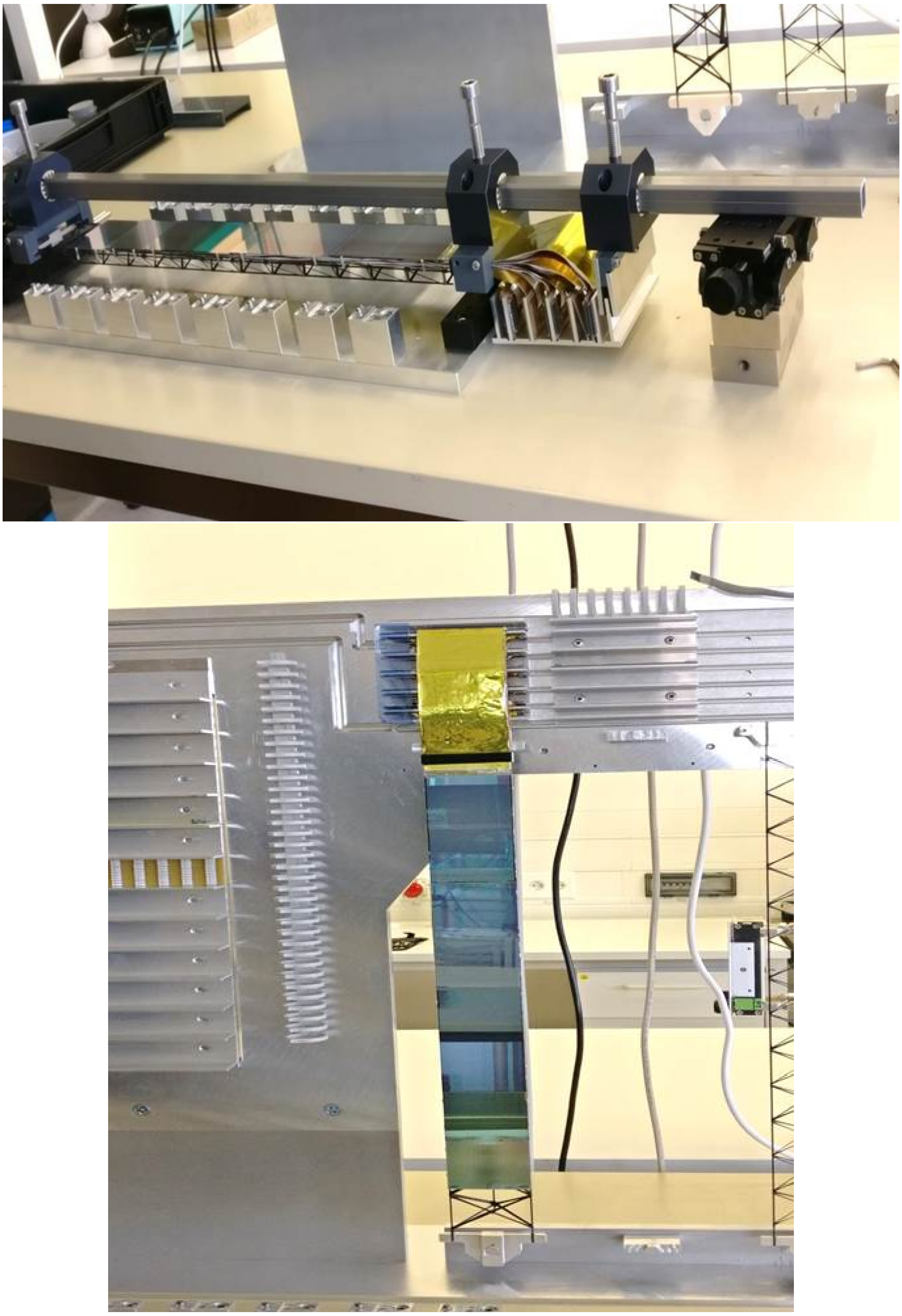

Figure 9: Testing ladder transfer from the assembly fixture to the mounting position on a C-frame using mockup parts fitting the size of a a quadrant of CBM-STS largest tracking stations.

5 Summary

Ladder assembly for the silicon tracking systems of the experiments *CBM at FAIR* and *BM@N at Nuclotron* has been developed from the conceptional phase as laid out in the CBM-STS Technical Design Report to the proofing in the pre-curser experiment *mCBM at GSI-SIS18* and the subsequent approval for production readiness in the CBM-STS project during the Core-Review in December 2018. Two technical approaches for ladder assenbly have been worked out, using the same detector components, i.e. the same detector module structure and carbon-fiber supports. The JINR approach uses a complex assembly device based on ten precision stages for 3-dimensional alignment of ten detector modules, and an optical system to control the alignment, after which the carbon space frame is attached to the modules. The GSI approach uses a more streamlined set of precision-machined tools, realizing a serial attachment – module by module – to the carbon fiber space frame. It relies on precision-cut sensor edges and an optical survey of the sensors prior to module assembly and in particular after their installation onto the ladder. Studies with real components have demonstrated that the procedure works as intended and yields the targeted mechanical tolerances of the sensor positions. For some of the components, different manufacturing details are applied, but yielding objects of the same critical dimensions and properties. For the mSTS ladders, the GSI approach has been selected to produce and proof the first ladders for mCBM start-of-running in 2018. It is planned to have ladders from JINR-VBLHEP production available for application in mSTS in 2019, as well as for the initial installation in the STS of the BM@N experiment at JINR.

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