Overview of the Silicon Tracking System for the CBM experiment

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Abstract. The Compressed Baryonic Matter (CBM) experiment will explore the QCD phase diagram in the region of high net baryonic densities and moderate temperatures. CBM will start it's physics program at the SIS-100 and later at the SIS-300 synchrothrons which will deliver beams for heavy ion collisions at energies up to 45 AGeV with hit rates up to 10 MHz. The Silicon Tracking System (STS) is the core tracking detector of the experiment. It will be used for the reconstruction of the tracks of charged particles and determination of their momenta. For this task eight tracking stations constructed with double-sided sililcon micro-strip sensors will be accomodated downstream the target inside the superconducting magnet. The required momentum resolution for particles with momenta above 1 GeV/c is of the order of Δp/p = 1 %. To aim this, the material budget should be reduced to the level of 1% X_0. The STS will provide track reconstruction efficiency for fast primary tracks on the level of 95 % and higher. In this paper, the detector concept is summarized along with the detector components and simulation of the system's performance. Also, the quality assurance tests of the silicon sensors in which the author is involved in, are presented.

1. The CBM experiment

The CBM experiment is one of the four large experiments of the new Facility for Anti-proton and Ion Research (FAIR) that will be built at GSI, Darmstadt [1]. CBM is an experiment with a comprehensive physics program about the formation of matter, quark-gluon plasma (QGP), the nature of the transition between QGP and hadronic gas, the search of the critical point, and others. To achieve this, heavy nuclei accelerated in the SIS-100 and later in the SIS-300 synchrothrons to energies from 2 to 14 GeV/nucleon and up to 45 GeV/nucleon, respectievly, will be collided with nuclear targets yielding interaction rates up to 10^7 collisions/sec. The showers of charged particles created in these collisions will flow into the CBM detector systems and will be reconstructed and identified. The experimental challenge is to measure particles and multi-differential observables including multi-strange hyperons and so called rare probes such as short-lived light vector mesons (ρ, ω, ϕ) and charmonium (J/ψ) with unprecedent precision and statistics.

2. The Silicon Tracking System

2.1. Detector concept

The Silicon Tracking System (STS) will be located inside the superconducting dipole magnet comprising 8 tracking stations between 30 cm and 1 m downstream of the taget. The task of STS is to reconstruct the tracks of all charged patricles flying through the detector after the beam-target interactions and to determine their momenta. This requires large detector acceptance to cover rapidities from center of mass to beam rapidity. This is implemented in the STS as a polar aperture from 2.5° to 25° (Fig. 1). According to UrQMD simulations of Au-Au collisions at 25 AGeV, around 1000 charged particles will be created per central interaction and around 800 of them will be captured by the detector's acceptance (Fig. 2). With the double-sided microstrip sensors having strip pitch of 58 μm, the single-hit resolution is identified to be around 25 μm, which will provide the required momentum resolution on the level of Δp/p = 1 % for particles with momenta above 1 GeV/c. For particles with the same momentum, the track reconstruction algorithms shall enable the trajectory finding with efficiencies exceeding 95 % [2].

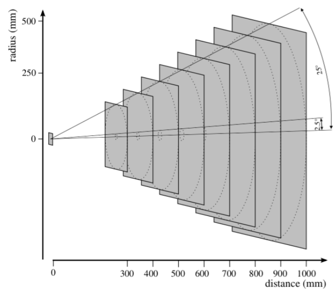


Figure 1: STS stations concept.

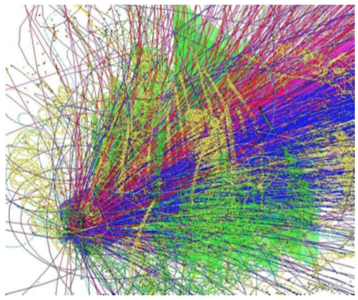


Figure 2: A simulated Au-Au collision at 25 AGeV energy with about 1000 charged particles produced.

In the inner parts of the stations hit rates up to 10 MHz/cm^2 are expected. Sensors of three different sizes have been chosen for different areas of the stations to keep the maximum strip occupancy at the level of a few percent. All sensors will be read-out via ultra-thin microcables by readout electronics outside of the physics aperture, restraining the material budget of about 1% X_0. A high level of radiation damage is expected to impact on the sensors. Beyond the maximum exposure with 1× 10^{14} in 1 MeV neutron equivalent that will be reached after several years of running depending on the physics program, the replacement of the sensors is planned.

2.2. Detector components

The combination of either a single silicon sensor or a daisy-chained set of two sensors with attached micro-cables and two readout electronics boards form the *module* (Fig. 3). A module is the smallest assembled functional unit of the STS. Modules of different types will be built due to varying sizes of sensors and different lengths of readout cables. The modules will be arranged on carbon fiber supporting structures, forming ladders, and futher half-stations which will be mechanically and electrically integrated into tracking stations (Fig. 4).

Each station will be built from 300 μm thick double-sided n-type silicon microstrip sensors in three different sizes. The double-sided technology was chosen according to avdanced space-point determination in the same amount of silicon material, in contrast with two back-to-back single-sided sensors having strips implemented only on one side, obeying the low-mass requirement. The sensors have a stereo angle of ± 7.5° between the front and back side strips, providing the optimal spatial resolution in the magnet's bending plane, along the horizontal axis. The neutron equivalent fluence in the detector, expected to be lower than 1 × 10^{14} n_{eq} cm^{-2} for the harshest running scenario of the experiment at SIS-300, makes double-sided sensor technology applicable for the STS.

Very thin low-mass micro cables will be used to deliver signals from the sensors to the front-end electronics. The design of the cables has been chosen such that the capacitive impact of

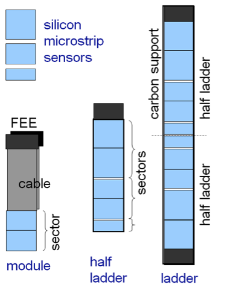


Figure 3: STS building blocks.

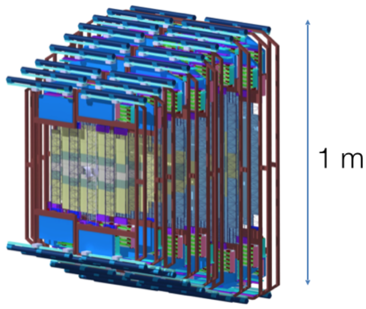


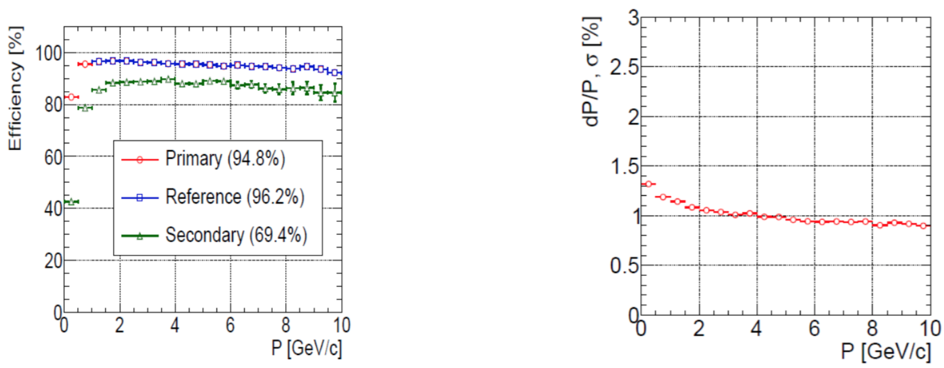
Figure 4: View of the assembled tracking stations.

the cables on the transmittable signal is on the minimum level, achieved by implementing an additional spacer layer between the conducting layers [2].

The read-out electronics of the STS will be based on the custom-designed self-triggering STS-XYTER ASIC. It will provide both timing and amplitude information for the signals transmitted from the sensors. For this, the chip will have two different signal processing chains: fast and slow. The fast path, optimized for the determination of the arrival time of the input charge comprises a fast shaper with the 30 ns peaking time, a dicriminator, a pulse stretcher and a time stamp latch. The slow path, optimized for low noise and accurate energy measurement, consists of a slow shaper with the 80 ns peaking time, a 5-bit flash ADC, and a digital peak detector [3].

2.3. Detector perfomance simulation

In the STS, the reconstruction of charged particles tracks is based on the Cellular Automaton (CA) track finder method using the registered hits.



(a)

(b)

Figure 5: Track reconstruction efficiency (a) and momentum resolution (b) in the STS as a function of momentum for all tracks in central Au-Au collision at 25 AGeV.

The Kalman Filter (KF) based track fit is used for precise estimation of the track parameters. The detailed information about CA and KF algorithms can be found in [4]. The track finding procedure is organized in several iterations that make the reconstruction fast and reliable in presence of a high track density: the high-momentum primary tracks are reconstructed at the first iteration, then the low-momentum primary tracks and finally all other tracks. The short-lived particles, which decay before reaching the tracking stations or inside the STS, can be reconsructed only via their decay products. The KF particle finder, which is based on the KFParticle package is used in order to find and reconstruct the parameters of short-lived particles by combining already found tracks of the long-lived charged particles. Figure 5 exhibits the track reconstruction efficiency and momentum resolution of charged particles as a function of particle momentum, calculated using the CBMROOT framework with CA and KF packages implemented. The simulated values of these parameters show good agreement with system requirements.

3. Quality Assurance for the silicon sensors of the STS

The STS will comprise 1220 silicon micro-strip sensors. Thus, three different quality assurance centers located at GSI, at the University of Tübingen (Germany), and at Dubna (Russia) are being equipped for quality assurance tests of the silicon sensors, the readout micro-cables and the detector modules after the mass production of the STS components. For the quality assurance of the sensors, a test stand has been set up in the cleanroom environment of GSI's Detector Laboratory with temperature and humidity control. The setup includes a wafer prober yielding a movement precision of 1 μm and number of devices for measurement of passive electrical characteristics of the sensors. The variety of quality tests that are being performed at the moment for STS prototype sensors include visual inspection, current-voltage and capacitive-voltage tests to check the general health of sensors, and detailed tests, in partucular the quality tests of each single strip. The latter requires automatization of the measurement procedure. For this, the author developed a dedicated LabView software which communicates with the wafer prober and allows performing single-strip measurements by stepping over all strips and extracting passive electrical parameters [5]. The manufacting process of double-sided silicon strip sensors is a complicated procedure during which several defects of the single strips are possible to be created. The developed software allows identifying defects of the strip such as

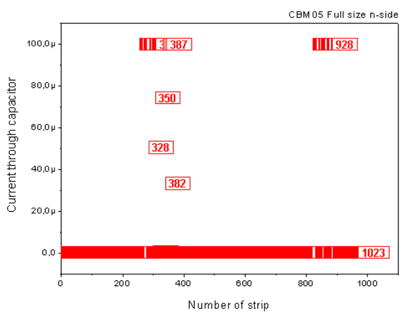


Figure 6: Pinhole test of the CBM05 sensor prototype.

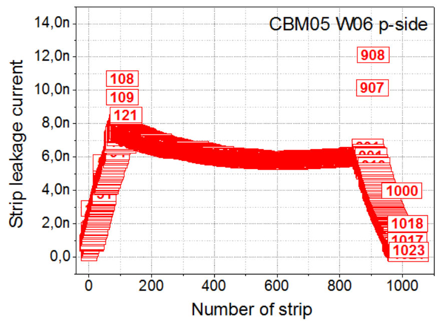


Figure 7: Measurement of the strip leakage current distribution of the CBM05 sesnor prototype.

pinholes, shorts between neighbouring metal strips, metal or implant breaks, and also measuring important parameters such as coupling capacitance and strip leakage current. Figure 6 illustates the result of a pinhole test for the junction side of the a prototype sensor pointing a large amount of pinholes found. The measurement is being done by contacting one by one the strip's DC and AC pads with two needles and measuring the current after a voltage of 20 V is applied. The origin of those defects turned out to come not from the manufacturing process but from a pronounced scratch on the sensor surface. Figure 7 depicts the measured leakage current distribution of each single strip on the junction side of the the prototype sensor. Due to the presence of the stereo angle the strip lengths decrease from the center to the corners. The leakage current is proportional to the strip lengths.

3.1. Long-term stability of sensors
The Silicon sensors of the STS will be operated during long periods of time continuously. Because of that the stability of their operation becomes important. The sensor is considered to be stable if it's leakage current does not deviate from the saturation value in time considering the temperature and humidity to be constant. Measurement of the long-term stability can be

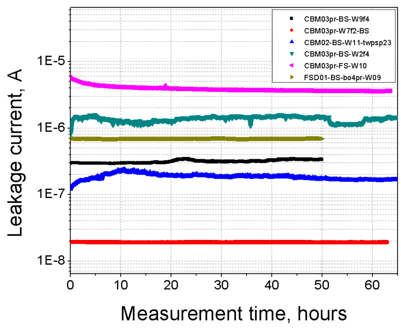


Figure 8: Long-term stabililty test of the CBM sensor prototypes.

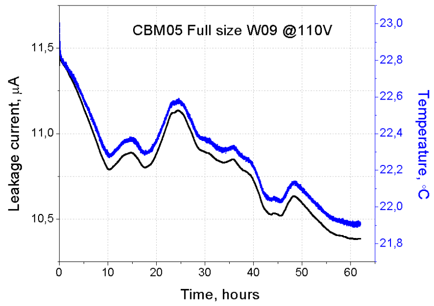


Figure 9: Leakage current and temperature monitoring.

performed under laboratory conditions by monitoring the leakage current of the sensor for a substantional period of time. The dedicated LabView software has been developed for leakage current stability tests of STS sensors. It allows monitoring of the leakage currents and correcting them for their temperature and humidity dependence. Temperature and humidity monitoring was implemented in the software as well due to the fact that the leakage current has strong temperature dependence. Results of the long-term stability tests for different sensor prototypes are shown in Fig 8. The behavior of the curves with slight deviation from flatness can be explained by temperature change impact which is shown in detail in Fig 9.

4. Conclusions
This overview of the Silicon Tracking System of the CBM experiment introduced the detector concept and the detector components. Simulation studies of the system perfomance show that the STS is able to meet the requirements for momentum resolution and track reconstruction efficiency. The results of the developed Quality Assurance testing procedures that are being performed to current prototype sensors has been shown. The Technical Design Report of STS has been approved in 2013. The production of STS components starts in 2015.

Acknowledgments
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