Performance simulations with a realistic model of the CBM Silicon Tracking System

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Efficient charged-particle tracking and high momentum resolution are central performance requirements of the CBM Silicon Tracking System (STS). The aim of the ongoing layout studies is to design a highly granular and low-mass detector system which can track up to 1000 charged particles that are typically generated in one central Au+Au collision at 25 GeV/nucleon projectile energy.

Detector layout

The STS comprises eight tracking stations located at 30, 35, 40, 50, 60, 75, 95 and 100 cm downstream of the target (Fig. 1). The stations have a modular structure and are constructed from 300 μm thick double-sided silicon microstrip sensors. Groups of sensors (sectors) are individually read out with electronics located at the perimeter of the stations. The number, position and segmentation of the layers are optimized for efficient track reconstruction and high momentum resolution. On the other hand, from the point of view of mass production and logistic, it is highly desirable to limit the number of different sensors and ladders to the minimum possible.

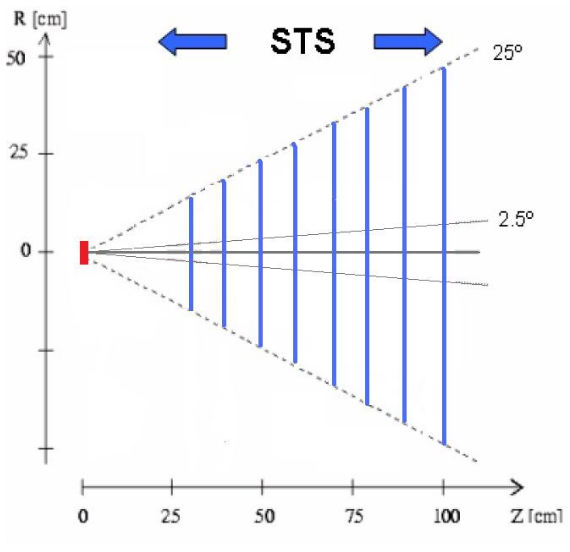

Figure 1: Schematical side view of the STS system

Material budget

The silicon detector is designed minimizing the total amount of material: the silicon sensors have the minimum thickness capable to provide a good signal-to-noise ratio, namely 300 μm. The simulated amount of material for the STS corresponds to $0.3\%\ X_0$ for the silicon sensors; a comparable effective thickness is added by the cables, where the simulated amount of material is equivalent to 70 μm silicon, giving $0.08\%\ X_0$ for every cable layer. A maximum value of approximately $1\%\ X_0$ is reached in the outer parts of every station, where eight layers of cables overlap. Adding the cable material into the simulation worsens the momentum resolution from 1.1% to 1.5%.

Silicon sensors

The full STS will use only four types of silicon sensors. In the innermost parts of the first three stations, where the particle occupancy is expected to reach 5%, 2 cm long strips were chosen to minimize the number of ghost hits. However, to reduce the material budget in the regions where the occupancy is lower than 5%, it is possible to use up to three 6 cm long sensors chained together, thus creating an effective strip length of up to 18 cm.

The expected strip occupancies and the required spatial resolution suggest a strip pitch of 60 μm. A value of 58 μm was chosen here, because it allows to divide the sensitive width of the sensor into 1024 strips, corresponding to 8 read-out chips of 128 input channels each. On either side of the double-sided sensor the strips are tilted by $+7.5°$ or $-7.5°$ with respect to the vertical edge, creating $15°$ stereo angle between the opposite sides. This allows to reconstruct multiple hits from the same sensor at the expense of a poorer spatial resolution in the vertical direction, keeping high resolution in horizontal direction for better reconstruction of the particle momenta in the 1 T dipole field.

Station layout

For all stations the full height of the sensitive area can be covered by vertical ladders of ten sectors (see Fig. 2). Neighboring ladders overlap by 5 mm in order to avoid dead space caused by the guard ring structures of the sensors. The number of ladders was chosen to cover $25°$ acceptance. In order to cover the targeted $25°$ acceptance as closely as possible, the outer parts of stations 2-8 are equipped with ladders from previous stations. The presented layout allows to construct the full STS with only eight types of ladders. The total number of sensors, ladders and read-out channels are summarized in Table 1.

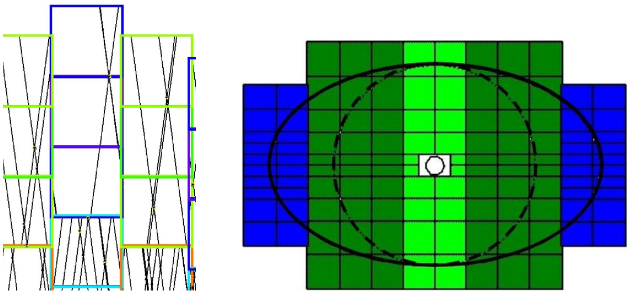

Figure 2: Left: Event display showing active strips in one of the STS stations; the stereo angle between front and back strips is 15°. Right: Second STS station, placed at 40 cm downstream from the target. Different colors represents different ladder types. Each ladder is built from ten sensors. The dashed circle corresponds to 25° geometrical acceptance, the solid ellipse to a horizontally extended acceptance in order to provide efficient reconstruction of low-momentum electrons.

Table 1: Summary of STS components

Station	Ladders	Sectors	Sensors	R/O chips	Channels
1	8	80	80	1280	164k
2	12	120	120	1920	247k
3	12	120	120	1920	247k
4	14	136	172	2176	279k
5	14	136	156	2176	279k
6	14	136	192	2176	279k
7	16	156	220	2496	319k
8	16	156	232	2496	319k
Total	106	1040	1292	16640	2133k

For comparison, a purely geometric estimate of the minimal number of read-out channels required to cover the geometrical acceptance of $2.5° - 25°$ at a maximal sensor occupancy of 5% yields 12k read-out chips. The difference between this estimate and the number of r/o chips quoted for the proposed layout is mainly due to the necessity to limit the number of different sensors and ladders to the minimum possible.

Performance studies

The layout presented above was used to implement the STS in the CBM simulation framework. This implementation includes the complete chain of physical processes caused by a charged particle traversing the detector from charge creation in the silicon to the digitial output signals. The first step of STS hit reconstruction is performed by an algorithm called cluster finder. A cluster is a group of signals caused by a particle traversing a portion of the detector. A signal has to pass a threshold to be taken into account, otherwise it is rejected. In the STS case, the threshold is constant for every channel and equals 4000 e^-. The accepted signals coming from adjacent strips of a sensor side are grouped together in a cluster. The total charge of a cluster is defined as the sum of the single strip signals. The cluster position is given by the center-of-gravity [1] equation

$$X_{COG} = \frac{\sum\limits_{cluster} S_i x_i}{\sum\limits_{cluster} S_i} \tag{1}$$

where x_i is the position of the i^{th} strip included in the cluster and S_i the signal on this strip; the sums runs over all strips included in the cluster.

In the next step, the association of two clusters lying on the opposite sides of the double-sided sensor is performed. The last step defines the hits and their properties.

Applying realistic detector response functions [2] such as:

- ▷ signal sharing between strips
- ▷ charge collection inefficiency
- ▷ Lorentz shift due to presence of the magnetic field
- ▷ channel dead time
- ▷ random noise added to the charge signal

together with a Cellular Automaton for track finding and a Kalman Filter for track fitting, results in a track finding efficiency of 97% for fast primary tracks and 75% for secondary tracks, with a momentum resolution of 1.1%. These results were obtained with a noise width of 0.5k electrons and a charge threshold level of 4k electrons.

Since the granularity of the detector changed in comparison to the one presented in [3], the time for track reconstruction of central Au+Au collisions decreased from 3.6 to 2.3 seconds per event on a single-core CPU. The STS granularity has also a strong impact on number of combinatorial hits. It was possible to reduce the number of ghost hits by 10%.

Conclusions

The simulations described in this report take into account the properties of the STS detector. The results obtained with our algorithm indicate a preference for a detector geometry with high granularity. As far as the predictions of realistic cable thickness are correct, the results obtained clearly show that the solution with a minimum number of different ladders is the preferred one from the point of view of performance and maintenance. However, the external constrains that define the size of STS stations are not yet finally defined. Consequently, details of the layout may be subject to change.

References

[1] V. Bartsch *et al.*, Nucl. Instr. Meth. Phys. Res. **A 497** (2003) 389

[2] A. Kotynia, J. M. Heuser and W. F. J. Müller, *CBM Progress Report 2009*, Darmstadt 2010, p. 7

[3] A. Kotynia and J. M. Heuser, *CBM Progress Report 2009*, Darmstadt 2010, p. 6