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Silicon tracker simulation for the Turkish Accelerator Center particle factory

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ABSTRACT

The tracker part of the Turkish Accelerator Center super charm factory detector is composed of 10 silicon strip detector planes supported with carbon layers. In this work, FLUKA simulation results of momentum, energy and position resolutions are presented for this structure. These simulations show that the silicon tracker design is suited for the requirements given by the charm factory physics program.

1. Introduction

The Turkish Accelerator Center (TAC) will be a regional facility for accelerator based fundamental and applied research in Turkey. One of the main parts of the TAC project is a super charm quarks particle factory (PF) based on colliding a 1 GeV electron beam against a 3.5 GeV positron beam, designed as a linac-ring type collider at the center of mass energy of 3.8 GeV. The super charm factory with luminosity $L = 10^{35}$ cm^{-2} s^{-1} will give opportunity to investigate charm physics well further than B factories benefiting from a boost parameter ($\beta\gamma = 0.68$) for some processes [1]. The TAC PF detector is configured around a 1 T superconducting solenoid magnet for precise momentum measurements of charged tracks. Tracking and momentum measurements for charged particles will be made by silicon strip detectors. Charged particles are identified with a time-of-flight system, located outside the silicon tracker, in conjunction with dE/dx measurements done in the tracker. The energies of electromagnetic showers are measured by a crystal calorimeter placed outside the time-of-flight system and inside the magnet. Muons are identified by a muon system that consists of layers of resistive plate chambers inserted in gaps between steel plates of the steel magnetic flux return yoke as in the BES III detector [2].

It is important to measure the particles' momentum over a wide rapidity range with excellent resolution to provide excellent separation in order to identify the scattered particles. The proposed tracker system should provide precise position measurements. The energy loss measurements in the tracker can also provide additional information on particle identification, and the precision of dE/dx measurements is proposed around 5% for particles with an incident angle of 90°. In the present work, in order to calculate the particle momentum, energy and position resolution values for the designed tracker system, a FLUKA simulation code was used to simulate the charged particles passing through the tracker in a 1 T magnetic field.

2. TAC PF tracker structure

Silicon is the dominant sensor material in the new build tracking detectors for excellent momentum and position resolutions, and dE/dx measurements. A silicon tracker system was designed for the TAC PF detector for effectively tracking of the relatively low momentum charged particles. The initial design of the tracking detector consists of five individual cylindrical barrel modules with 4 cm distances between them. Each module has two parallel single-sided silicon strip detector planes assembled into carbon layers, with a distance of 2 cm between them. The cylindrical barrel part of the tracker consists of about 9000 detector elements in total as shown in Fig. 1.

The typical silicon strip detector has a surface dimension of about 6×6 cm^2, a thickness of 200 μm and a pitch width of 50 μm. The inner and outer layers of the tracker have different detector modules because of the particle flux changing with the distances from the interaction point. The tracking detector occupies the region between a radius of 8 cm and 34 cm and the z extent of the barrels increases with the radius as given in Table 1.

The tracker located around the interaction point is tiled with silicon strips and covers the range of pseudo-rapidity $\eta < 2.1$. The TAC PF detector components and tracker layout are displayed in Fig. 2.

As the tracking detectors surround the interaction point, they could suffer from radiation damage in the harsh radiation environment. Traversing particles not only ionize the silicon lattice but

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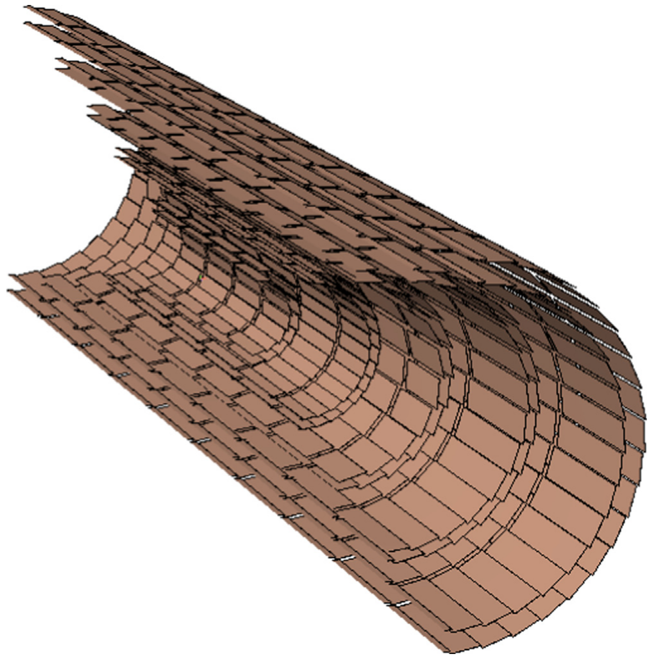

Fig. 1. Schematic view of the silicon tracker detector.

Table 1
The layers' radii and their z extents of the tracker.

	Radius (cm)	z Extent (cm)
1–2 layers	8.00–10.00	32.0
3–4 layers	14.00–16.00	56.0
5–6 layers	20.00–22.00	80.0
7–8 layers	26.00–28.00	104.0
9–10 layers	32.00–34.00	128.0

also interact with the atomic bodies via the electromagnetic and strong forces. Radiation damage studies on tracker silicon detectors are being carried out, but considerable damage is expected due to the low momentum of incident particle.

3. Momentum resolution

The homogeneous solenoidal magnetic field B bends the charged particle track because of the Lorenz force. The radius of the track, perpendicular to the magnetic field, is proportional to the transverse momentum p_t and the charge q of the particle. The deviation from the straight line path is defined as the sagitta which is given by [4]

$$s = \frac{0.3 \cdot L^2 \cdot B}{8 \cdot p_t} \tag{1}$$

where L is the lever arm defined as a distance between the first and last track points. Eq. (1) implies that the relative transverse momentum resolution is the same as the relative sagitta resolution. Thus the relative resolution of the transverse momentum can be given by [4]

$$\frac{\sigma_{p_t}}{p_t} \equiv \frac{\sigma_s}{s} = \frac{8 \cdot p_t \cdot \sigma_s}{0.3 \cdot B \cdot L^2} \tag{2}$$

where σ_s is the sagitta measurement error which depends on the spatial resolution of the individual measurement point. As can be seen from Eq. (2), the momentum resolution becomes worse increasing p_t because tracks curve less, and improves as $1/(B \cdot L)^2$ [4].

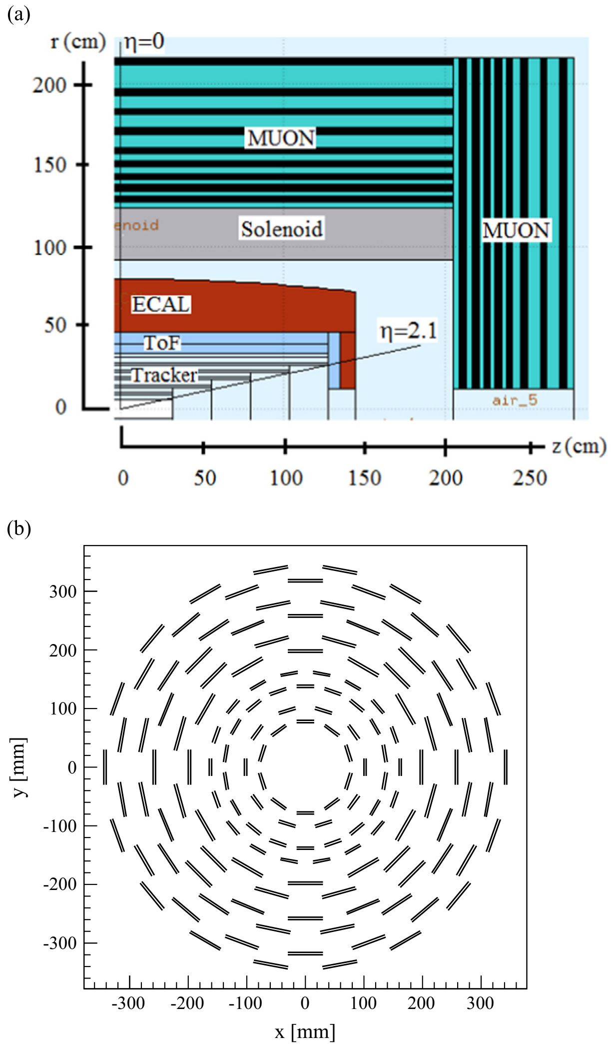

Fig. 2. (a) Overview of the Si tracker detector geometry and (b) x–y view of the tracker arrangement drawn using tkLayout which is a software package for tracker layouts developed by the CMS group [3].

In fact, the charged particle trajectories inside the tracker are perturbed by the presence of material, causing mainly multiple Coulomb scattering (MS). This gives an additional uncertainty in the momentum measurement. The multiple scattering contribution to the relative p_t resolution is

$$\frac{\sigma_{p_t}}{p_t} = \frac{0.05}{B \cdot L}\sqrt{\frac{d}{X_0}} \tag{3}$$

where d is the tracker thickness and X_0 is the radiation length. This contribution is independent of the momentum and gets worse with increasing Z due to the reduction in radiation length, and improves as $1/(B \cdot L)$ [5]. The total momentum resolution is a quadratic sum of the two contributions:

$$\frac{\sigma_{p_t}}{p_t} = \frac{8 \cdot p_t \cdot \sigma_s}{0.3 \cdot B \cdot L^2} \oplus \frac{0.05}{B \cdot L}\sqrt{\frac{d}{X_0}} \tag{4}$$

4. Simulation

The FLUKA software described in Refs. [6,7] was used to simulate the charged particles at the different energies passing through the designed tracker system in a 1 T magnetic field at the

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