Proposal of the Muon System for the Super Tau-Charm Factory

Timofey Uglov[1,*]

[1]P.N. Lebedev Physical Institute of the Russian Academy of Sciences

Abstract. The first results of the Super Charm-Tau factory muon system simulation are presented: estimation of the main characteristics such as space resolution and muon identification efficiency. A design of the muon system for the Super Charm-Tau factory based on the organic scintillator + WLS fiber + SiPM is proposed.

1 Introduction

The Super Charm Tau-factory (SCTF) [1] is a future electron-positron collider operating in the range of center-of-mass (c.m.) energies from $2\,\mathrm{GeV}$ to$5 \div 6$ GeV with a high luminosity of about $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. In this energy range practically all states with charm can be produced including charmonium, bound states of c and $\bar{c}$ quarks, charmed mesons and baryons comprising one $c\,(\bar{c})$ quark. In addition, at the c.m. energy above $2m_\tau \approx 3.6\,\mathrm{GeV}$ τ lepton pairs can be produced. Because of its extremely high luminosity such a collider will be a copious source of charmed particles and τ leptons.

The main goal of experiments at SCTF is a study of the processes with c quarks or τ leptons in the final state using data samples that are at least two orders of magnitude higher than those collected by the CLEO-c [2] and BESIII [3] experiments. The desired luminosity corresponds to approximately 10^9 τ leptons, 10^9 D mesons and a 10^{12} of J/ψ mesons. The total integrated luminosity planned to be collected at the SCTF factory is $10\,\mathrm{ab}^{-1}$. These data samples will allow a systematic study of all states composed of quarks of the two first generations (u, d, s and c) as well as searches for exotic states. Huge data samples will also allow a search for principally new phenomena, such as CP violation in the D meson system and in τ leptons as well as lepton flavor violation with high sensitivity.

The design of the detector for the SCTF is not fixed now. Below we discuss the first results of the simulation of the muon system – one of the main SCTF detector's subdetectors.

2 Requirements to the muon system

Being a part of the SCTF detector, muon system should both compile with the general requirements, such as high acceptance and efficiency, and provide muon system specific services. Among them are muon identification (muon/pion separation), K_L registration and identification, and K_L veto. To take on this challenge we plan to construct multilayer system with

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[*] e-mail: uglov.timofey@gmail.com

detector layers interspersed with absorber material such as steel. The use of steel as an absorber could be explained by the fact, that it will be also utilized as flux-return yoke for the superconducting magnet. The choice of the particle detector technology, desired space and time resolution, number of layers and width of the absorber are the subjects of R&D studies.

3 Simulation

One of the most important and urgent tasks for muon system technology choice and further optimization is to create and to use a fast and reliable simulation tool. Optimal toolkit in this case is pure Geant4 simulation with simplified geometry and physics lists able to produce fast results and estimate main parameters and characteristics of the detector.

The space resolution of the system totally depends on the type of the detectors and, therefore, resolution estimation is a cornerstone of the technology choice process. The the muon/pion smearing due to the multiple scattering depends on the particle energy, detector's design and magnetic field. To find the smearing and study the feasibility to distinguish pion and muon based on the information of the last layer achieved by the particle, the geometry shown in Figure 1 a), is used:

- For simplicity, only the barrel part of the detector was simulated.
- The simplified design includes the following elements only:
  - CsI calorimeter (inner radius 1090 mm, thickness 297.6 mm, which corresponds to 16 radiation lengths (X_0).
  - Magnet coil (inner radius 1610 mm, thickness 14.4 mm of copper, which corresponds to $1X_0$).
  - 9 iron absorber layers in octant geometry (see the drawings). The distance to the innermost layer is 1900 mm from the beamline, thickness of the absorber layers are 30 mm, 30 mm, 30 mm, 40 mm, 40 mm, 80 mm, 80 mm, and 80 mm, respectively, which roughly corresponds to $1.7\,X_0$, $1.7\,X_0$, $1.7\,X_0$, $2.3\,X_0$, $2.3\,X_0$, $4.5\,X_0$, $4.5\,X_0$, and $4.5\,X_0$.
  - The 30 mm gaps between the absorber layers are sensitive detectors for the particles.
- Internal elements of the detector are estimated to give from $0.35\,X_0$ to $0.6\,X_0$ in total and are neglected in this study.
- Magnetic field is not simulated.

The Monte Carlo simulation shows, that the unavoidable smearing of the muon tracks, originating from $J/\psi \to \mu^+\mu^-$ decays, for the innermost layer of the muon system reaches 4.2 cm. It is mainly stipulated by the multiple scattering in the CsI calorimeter. The smearing at the last layer raises up to 6.5 cm. These results limit the required space resolution of the detector to be > 4 cm. The possibility of the π/μ identification has been studied with the following algorithm: the difference between last layers, reached by pions and muons of the same energy was compared. Since muon penetration possibilities are larger, than pion ones, positive values correspond to the effective identification, while negative – to fakes. The corresponding plot for muons and pions of 1 GeV/c momentum is shown in Figure 1 b). The large number of non-informative zero values could be explained by the fact, that both 1 GeV/c pions and muons loose the major part of its energy in the calorimeter and thus do not reach the first layer. The used π/μ separation algorithm is very rough and have been used for demonstration purposes only. It will be replaced with much more efficient and sophisticated identification procedures.

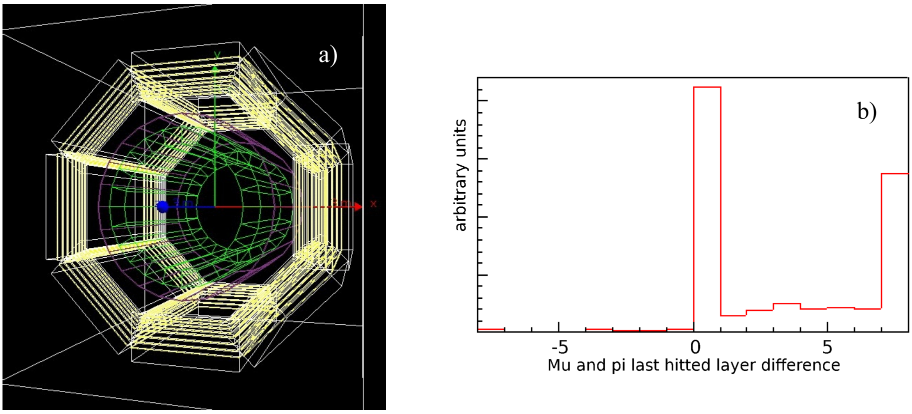

Figure 1. a) Simplified detector design used for simulation. CsI calorimeter is drawn with the green lines, while superconducting magnet with magenta lines. White and yellow lines designate absorber and detector layers of the multilayer muon system, respectively. b) Difference in the number of the last layers, reached by pions and muons of the same momenta. Positive values correspond to the effective π/μ identification, negative to fakes. Zero values are non-informative.

4 Design proposal

Based on our previous experience with similar Belle II [7] K_L and muon system [4] and taking into account the discussed requirements, we propose the design of the SCTF detector muon system. The technology proposed for the detector is the combination of the polystyrene strips with scintillator dope as the detecting element. The emitted photons are to be captured by the wavelength shifting (WLS) fiber, glued into the groove of the strip, and than transported to the end of the strip. Silicon photomultiplier (SiPM) is used for the photon detection. Below we briefly describe the design of the Belle II EKLM system – proposed "prototype" for the STCF muon system.

The Belle II EKLM (Endcap detector for K-Longs and Muons) system is based on the scintillator strips equipped with the WLS fibers read out by the silicon photomultiplier operating in the Geiger mode. The entire system consists of 15600 strips assembled into 104 sectors and installed into the gaps in the segments of the Belle solenoid flux return. In the forward part of the detector all 14 gaps are filled with EKLM modules, while the backward part contains 12 layers only. Silicon photodetectors operating in Geiger mode were first used in particle physics for CALICE hadron calorimeter prototype (7620 channels) [5]. Hamamatsu MPPC S10362-13-050 sensor, $1.3 \times 1.3\,\text{mm}^2$ – a key element of the EKLM detector – was developed and produced in large amount (> 60000 devices) by Hamamatsu for the T2K [6] experiment. It was the first mass usage of MPPC's in a large scale experiment.

The construction of the strip is shown in Figure 2 a). The 7 mm thick polystyrene strips are produced by Uniplast (Vladimir, Russia) by extrusion which allows to manufacture long strips. The scintillation is provided by PTP (p-terphenil) and POPOP (1,4-bis-2-(5-phenyloxazolyl)-benzene) dopes. Being extruded, strip is cut to the proper width (4 cm) and length, its surface is covered with diffusion reflective coating by chemical etching. A groove is milled along the strip. Kuraray WLS Y-11(200)MSJ multi-cladding 1.2 mm diameter fibers are glued using SL-1 glue produced at SUREL (St. Petersburg, Russia). To improve the efficiency of the light collection by the WLS fiber a groove of the rounded shape is milled. This allows to avoid small residual air bubbles at the groove corners and thus increases the glue

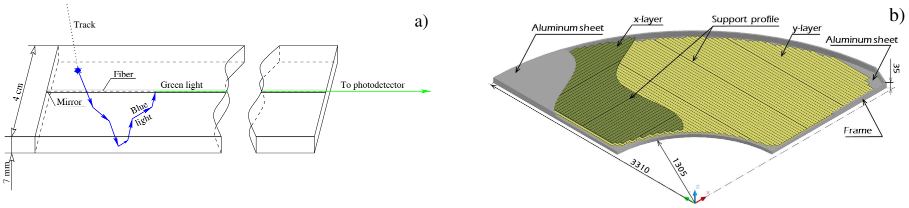

Figure 2. a) Construction of the scintillating strip with glued WLS fiber. b) Module construction.

transparency. Laboratory tests demonstrate an increase in the average detected light yield by (25 ± 5)% relative to the "standard" rectangular-shaped grooves. One of the ends of the fiber ('far end') is mirrored with silver-shine dye. Another one ('near end') is connected to the SiPM. The better optical contact between the WLS fiber and SiPM corresponds to the minimal air gap between the fiber end and the SiPM surface. The surface of the SiPM is covered with protective resin having concave shape due to the surface tension effects during the hardening of the resin. As a result, the light from the fiber is defocused at the SiPM matrix. The optimal length of WLS protrusion inside the meniscus is found to be $150\,\mu m$, which results in (37 ± 5)% increase of the number of photoelectrons, collected by SiPM, and still ensures no mechanical contact of the fiber end to the resin surface.

All produced strips were tested at cosmic ray stand to determine the quality of the strip assembly. The measured light yield appears to be almost two times larger, than it was expected by the TDR [7], and only a few strips were rejected. The measured time resolution of 0.7 ns allows to use Belle II EKLM system as a time-of-flight detector for K_L^0's. A EKLM module is constructed of two placed in orthogonal directions equal planes of 75 strips each, covered by 1.5 mm thick polystyrene substrate from both sides and placed in the module frame boxes previously used for Belle KLM RPC chambers (see Figure 2 b). In the middle part of the sector, unavoidable small dead zones (0.8%) are due to the presence of support structures. The total insensitive area between strips due to the reflective cover is only 0.3%.

5 Summary

In summary we have simulated response of the muon system of the STCF detector with the Geant4 based Monte Carlo technique with simplified geometry. It is demonstrated that space resolution of the detector limited by multiple scattering is ~ 4 cm. The design of the detector based on the organic scintillator strips with WLS fibers read out by SiPMs is proposed.

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