Development of an aerogel Čerenkov counter for the $\Sigma p$ scattering experiment

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We are planning to the $\Sigma p$ scattering experiments in J-PARC (J-PARC E40 experiment). The purpose of this experiment is to measure the differential cross sections of $\Sigma^+p$ and $\Sigma^-p$ elastic scattering and $\Sigma^-p \rightarrow \Lambda n$ inelastic scattering by detecting more than 10,000 scattering events. In $\Sigma^+p$ channel, we aim to verify a large repulsive core which is expected due to the Pauli repulsive principle in the quark level. In other channels, we aim to investigate the $\Sigma N$ interaction systematically. In J-PARC E40 experiment, $\Sigma$ will be generated by $p + \pi^\pm \rightarrow \Sigma^\pm + K^\mp$ reaction with $\pi$ beam. To tag $\Sigma$ generation, $\pi$ and $K^+$ are detected with K1.8 beamline spectrometer and KURAMA spectrometer. By the measurement of momentum vector of $\pi$ and $K^+$ and kinematic energy and track of scattered $p$, the $\Sigma p$ scattering event is detected.

Aerogel Čerenkov (AC) counter will be installed in the downstream of the target, to identify scattered $\pi$ and $K^+$, a trigger detector to remove scattered $\pi$ events on online reveal. Since using 20 MHz high intensity $\pi$ beam in this experiment, it is important to suppress the trigger rate by AC counter. This counter is required to have a $\pi$ detection efficiency of 98 % or more.

I decided the basic design of AC counter. The size of this counter is 480 mm $\times$ 400 mm $\times$ 80 mm and this counter is divided into 4 segments (Room1, Room2, Room3, Room4). Čerenkov light read out with 12 fine mesh Photomultiplier Tubes (PMT). As a radiator, we use a silica aerogel having refractive index of 1.10. The assumed rates in E40 experiment for Room1, Room2, Room3 and Room4 are 300 kHz, 300 kHz, 250 kHz and 40 kHz.

I made two prototype AC counter (diffuse and specular reflection type) to decide detail design and did the test experiment with $e^+$ beam at Research Center for Electron Photon Science (ELPH) Tohoku University. As result, the prototype of diffuse reflection has high performance (over 20 p.e. and 99.9% efficiency) at low beam rate. However, PMT gain decreased at high beam rate due to the increased current between the dynodes.

I made AC counter for J-PARC E40 experiment and did the test experiment with $e^+$ beam at ELPH. In order to avoid gain decrease, the voltage applied to the PMT was set low and the signal was amplified by PMT AMP. As a result, the detection efficiency of positrons at a rate of 300 kHz was over 98% when the threshold value was 6 p.e. or less.

The particle detected by AC counter is $\pi$. Therefore, I estimated the detection efficiency of $\pi$ by Monte Carlo simulation with Geant4. As a result, it was estimated that the detection efficiency of $\pi$ is over 98% when the threshold value is 6 p.e. or less.

Finally, I considered the setting of AC counter in the J-PARC E40 experiment. As a result, it is considered that the optimum PMT gain is 60 ch/p.e. and the threshold is 4 p.e.