Optimization of detectors position and Faraday cup for LAS upgrade

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Large Acceptance Spectrometer(LAS) is being upgraded in order to efficiently measure low energy particle (∼10 MeV/u), including forward-angle scattering in reactions such as $(\alpha, {}^6\mathrm{He})$ or $(\alpha, {}^6\mathrm{Li})$ at 100 MeV.

In this paper, we report the result of the optimization of detector positions to achieve sufficient momentum resolution and design of a Faraday cup for forward scattering measurements. To study the optimizations, we used GICOSY[1], an ion optics simulator that can drive a third-order transfer matrix, and MOCADI[2], a Monte Carlo simulator that can calculate particle orbits emitted from a given position, angle and momentum through the ion optical system defined by GICOSY.

1 Position of detectors

The LAS is a QD system and its detectors consist of two VDCs and two plastic scintillators. For the measurement of low-energy particles, thickness of detectors must be reduced. As a solution, the wires and thinner scintillators should be installed in a single chamber filled with low-pressure gas, which can reduce thickness of not only detectors but also partition membrane.

Under these conditions, it is considered to place the chamber at the exit of the dipole magnet, upstream of the focal plane, to reduce the chamber size. However, the upstream materials degrade the momentum resolution because multiple scattering defocuses the image on the focal plane. We investigated the effect of the multiple scattering and its position dependence.

The method of estimating the resolution is as follows. First, a simulation is performed to obtain the inverse matrix by singular value decomposition using scattering angle and momentum at the target, and the position and angle at the focal plane, for a subset of events without multiple scattering. Then, the simulation is repeated including multiple scattering: random numbers are generated for the angles at the material plane as an angular straggling and the image on focal plane is constructed. The momentum is reconstructed using the inverse matrix and the position and angle at the focal plane, and the residual between true and reconstructed momentum is evaluated. The correlation between the true and reconstructed momentum is shown in Fig. 1(a). The width of the residual is obtained as the momentum resolution as shown in Fig. 1(b).

In this study, we considered so-called standard optical system, and the angle and momentum at the target covered full acceptance of LAS. We assumed the membrane of 50 μm thickness Kapton between the vacuum and the gas and butane gas at 0.1 atm with a length of 20 cm for the detectors region. Position and angular resolutions of detectors were neglected. The straggling is estimated using LISE^{++} [3].

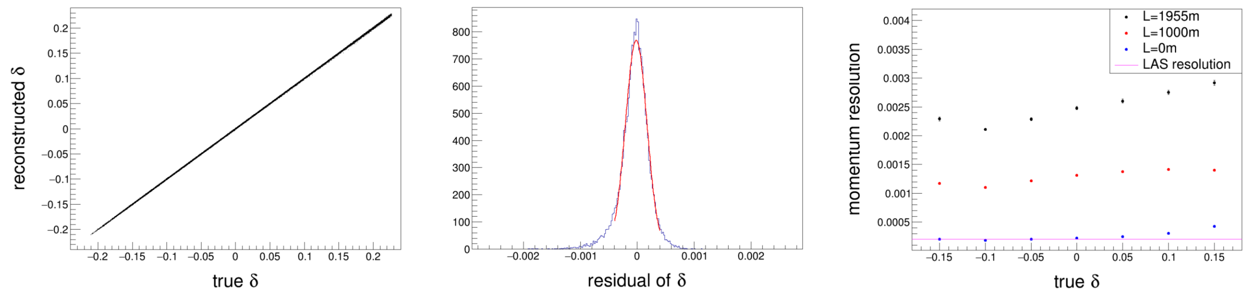
Fig. 1(c) shows the correlation between the momentum resolution and momentum. L in the figure is the distance between the membrane and the focal plane, that is, black points correspond to detectors placed at the exit of the dipole magnet, and blue points correspond to detectors at the focal plane. The pink line indicates the present resolution 1/5000. If the detectors are installed upstream, the momentum resolution becomes about 10 times worse, which is unacceptable.

In conclusion, detectors should be installed on the focal plane as in the current configuration. In addition, it was found that the membrane plays a critical role in the resolution, because its mass thickness and a distance to the focal plane are larger than those of the gas, resulting a larger position shift on the focal plane.

2 Faraday cup

For forward-angle measurements, where beam particle enter the spectrometer, a Faraday cup should be installed in the spectrometer. We studied appropriate design of the Faraday cup such that it can sufficiently stop the beam particles without preventing particles of interest from reaching the focal plane, by simulating the beam image on a given plane.

We assumed that the Faraday cup is installed in a duct downstream of the Quadrupole magnet and can be moved horizontally with a support and a motor. The distance between the scattering point and the Faraday cup is 1574.2 mm. Since the Faraday cup is located in the fringing field of the Quadrupole magnet, we reproduce this field in GICOSY to define 40 segments of magnets as the Quadrupole magnet, rather than using an effective field. The magnetic field distribution input is based on RCNP Annual Report (1992)[4].



(a) Reconstruction of momentum. **(b)** Residual of true and reconstructed momentum. **(c)** Position dependence of momentum resolution.

Figure 1: Momentum resolution. $\delta = (p - p_0)/p_0$.

We investigated the beam images for several conditions: the Quadrupole magnet field strength (standard focusing in the vertical direction,$\pm$20 %), the reaction channels ^{120}Sn(α, ^{6}He)^{118}Sn and ^{120}Sn(α, ^{6}Li)^{118}In, and beam angular offset: 0,$\pm$1,$\pm$3 mrad in the vertical direction. Beam properties on target is shown in Table 1. The angular and momentum spread consist of beam spread and straggling in the target(^{120}Sn,7 mg/cm^2). The

beam particle	α
beam energy	100MeV
energy spread	600keV
beam intensity	500enA
position spread	1 mm(vertical and horizontal,FWHM)
angular spread	5.6 mrad(vertical and horizontal,FWHM)
angular offset	0, $\pm$ 1, $\pm$ 3 mrad(vertical)

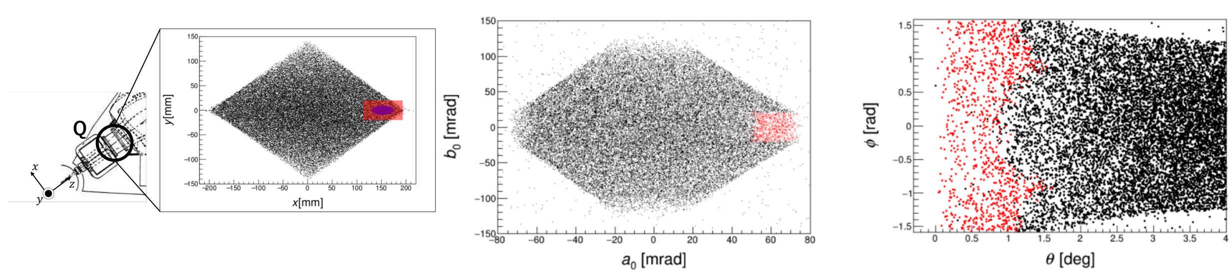
Table 1: Beam property.

LAS angle is 3.8 degree, which can shift the beam spot to one side.

The beam image and particles of interest (^{6}He or ^{6}Li) and the Faraday cup at the Faraday cup plane is shown in Fig. 2(a). The beam positions approximately follows a two-dimensional Gaussian distribution. The center and standard deviation are listed in Table2. The vertical angular offset affects center of y direction: $\pm$3 mrad offset changes the center position to about $\pm$3 mm.

Especially, in the case of (α, ^{6}He) at 100 MeV, the beam momentum lies within the acceptance. We determined the size of the Faraday cup based on the counting rate of beam particle which pass through the uncovered region and reach the focal plane. The acceptable counting rate is 10 kcps corresponding to the rate capability of the VDC. For beam intensity of 500enA ($\sim 10^{12}$ cps per wire), the Faraday cup should cover approximately 6.11σ of position distribution in both x and y directions, with additional +6 mm in y direction due to angular offset of beam.

In conclusion, the size of Faraday cup should be 40 mm(H) $\times$ 80 mm(W) including a margin. Such a Faraday cup in the spectrometer restricts angular region of measurement, as shown in Fig. 2(c). As a result, scattering angle of about 1.2 degrees and larger are measurable.



(a) x and y on the plane in which Faraday cup exist(black: particle, blue: beam, red:Faraday cup). **(b)** Angular acceptance of a_0(horizontal angle) and b_0(vertical angle) on the target. **(c)** Angular acceptance of θ and ϕ(polar coordinates) on the target

Figure 2: Position or angular distribution on each plane. Red area is covered with Faraday cup and unmeasurable.

$(\alpha, {}^6\mathrm{He})$		Q −20%	Q ±0%	Q +20%
x	center	158 mm	161 mm	163 mm
	sigma	5.1 mm	5.5 mm	5.9 mm
y	center	0 mm	0 mm	0 mm
	sigma	2.7 mm	2.4 mm	2.1 mm

$(\alpha, {}^6\mathrm{Li})$		Q −20%	Q ±0%	Q +20%
x	center	158 mm	159 mm	163 mm
	sigma	4.7 mm	5.1 mm	5.4 mm
y	center	0 mm	0 mm	0 mm
	sigma	2.9 mm	2.7 mm	2.5 mm

Table 2: Beam spot position and size on Faraday cup.

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