Status report on the developement of the high-resolution missing-mass spectroscopy for the (p,2p) reaction in inverse kinematics

S. Reichert,[*1,*2] M. Sako,[*2] M. Sasano,[*2] R. Gernhäuser,[*1] H. Baba,[*2] C. Berner,[*1] M. Böhmer,[*1] N. Chiga,[*2] W. F. Henning,[*4] T. Kobayashi,[*2,*5] Y. Kubota,[*2,*6] R. Lang,[*1] L. Maier,[*1] D. Mücher,[*3] V. Panin,[*2] L. Stuhl,[*2] E. Takada,[*7] T. Uesaka,[*2] L. Werner, [*1] and J. Yasuda[*2,*8]

A new detector setup for high-resolution missing-mass measurements was tested at the HIMAC facility in February 2016 with the reaction $^{16}\mathrm{O}(p,2p)^{15}\mathrm{N}$ in inverse kinematics at $E = 290$ MeV/nucleon and with a beam intensity of 10^5 pps. The concept is a detector setup having two arms each to measure the momentum vector of a proton emitted from the (p,2p) reaction. Each arm consists of three layers of single-sided 100 μm thick silicon detectors featuring a strip pitch of 100 μm. Two arrays of 9 scintillator rods for TOF mounted at a distance of 2 m outside the vacuum chamber for the target and silicon trackers complete each arm. Measuring the light particle's velocity $|\vec{v}|$ and their directions $\vec{v}/|\vec{v}|$, the missing-mass in a quasi-free scattering kinematic is defined rather well. Downstream in the beam-line, a $dE-dE$ detector measures the remaining heavy residues and therefore, one is even able to determine the exclusive excitation function. In the experiment, background especially arises from inelastic $(p,2p)$ reactions in the CH_2 target. For a detailed description of the setup, see[1)].

The major goal for the test experiment at HIMAC was to prove the capability of the setup to reach a resolution of $\sigma_{E_X} \sim 1$ MeV for the excitation energy. Achieving such a high excitation energy resolution is a major prerequisite for studying fission barrier heights induced by the $(p,2p)$ reaction in future experiments at RIBF/RIKEN.[2)]

Preliminary results for the resolution are for an opening angle of 3.2 mrad (σ_{open}) and for an energy of 3.3% (σ_{ENY}). They are slightly greater than the targeted values of 3.0 mrad (σ_{open}) and 2.5% (σ_{ENY}), respectively. The opening angle depends strongly on the inner-target multiple scattering. Therefore, 125-μm-thick target foils and vertical fiber targets ($D = 150$ μm) were accurately positioned to evaluate the vertex-position reconstruction performance of the silicon trackers. Geant4 simulations predict a vertex resolution of $\sigma_{pos} = 165$ μm. In the experiment we could reconstruct reactions in the fibers with a precision of $\sigma_{pos} = 175\,\mu$m[3)].

As a result of the quasi-free knockout reaction $^{16}\mathrm{O}(p,2p)^{15}\mathrm{N}$, we were able to demonstrate the missing-mass spectroscopy based on our setup by reconstructing kinetic curves for the ground state and the excited states at 6.3 MeV and 9.9 MeV with an uncertainty better than $\sigma = 1.7$ MeV, as shown in Fig. 1.

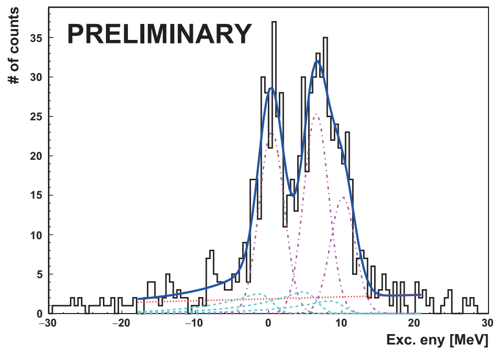

Fig. 1. Distribution of the excitation energies in ^{15}N, reconstructed from the missing-mass spectroscopy. Data are compared to a superposition of the three most prominent states and a constant background (red dotted line). Signal shapes were empirically fit by a gaussian (purple dotted) and a left tail (blue dotted).

The differential cross sections $d\sigma/dE_X$ are listed in Table 1 and so far do not match with the ratio of the spectroscopic factors in $(e,e'p')$ reactions in[4)].

Table 1. Comparison between preliminary diff. CS $d\sigma/dE_X$ and spectroscopic factors for the first discrete peaks

E_x (MeV)	J^π	CS Exp. (mbarn)	S_α Ref.[4)]
0.00	$\frac{1}{2}^-$	4.6±1	1.260(13)
6.32	$\frac{3}{2}^-$	5.2±1	2.348(19)
9.93	$\frac{3}{2}^-$	3.1±1	0.133(15)

The next step is the replacement of the first layer with new 50 μm silicon wafers to reduce multiple scattering and to improve the resolution of the missing-mass.

*1 Department of Physics, Technical University Munich
*2 RIKEN Nishina Center
*3 Department of Physics, University of Guelph
*4 ANL
*5 Department of Physics, Tohoku University
*6 Center for Nuclear Studies, University of Tokyo
*7 NIRS
*8 Department of Physics, Kyushu University

References
1) S. Reichert, M. Sako et al.: RIKEN Accel. Prog. Rep. 48, 47 (2015).
2) D. Mücher, M. Sasano et al.: RIBF NP-PAC-12 (2013).
3) L. Werner, Master's Thesis, *A silicon tracker system for (p,2p) reactions*, TU Munich (2016).
4) M. Leuschner et al.: Phys. Rev. C, 49,955 (1994).