PROPOSAL FOR EXPERIMENT AT SPring-8/LEPS: LEPS2001B

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TITLE OF A PROPOSAL: ϕ photo-production off the nuclei

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OBJECTIVES AND IMPACTS OF THE EXPERIMENT:

The primary objectives of the measurement off the nuclei are

1. to study the photo-production mechanism off the nuclei,
2. to obtain the ϕ-nucleon total cross section through the mean-free path of ϕ mesons in nuclei by using incoherent production process, and
3. to study ϕ-nucleon interaction by comparing the data from ϕ photo-production off the nucleon.

At GeV energies, particle production off the nuclei is very useful for obtaining the total cross sections of the unstable elementary particles. They are produced on one nucleon of the nucleus and then can interact with others before decaying. Thus the measurement of the production cross section in a wide range of the target mass number is advantageous to extract the total cross section with nucleon independently of the elemental production mechanism.

A few decades ago, mass number dependent cross section of ϕ meson photo-production off the nuclei was measured and the ϕ-nucleon total cross section was deduced as 12 mb, where the incident photon energies were $5 \sim 8$ GeV and the momenta of ϕ mesons are $5 \sim 8$ GeV/c. The coherent process is favored for forward angle ϕ photo-production at these high energies. The cross section was deduced by using the coherent process with the optical theorem [1, 2].

At low energies like SPring-8/LEPS, due to the finite value of minimum momentum transfer $|t|$ of the ϕ photo-production, the coherent process is considered to be suppressed comparing to the incoherent process. This was confirmed for the carbon target during the construction beam time. We have to study the reaction mechanism of ϕ photo-production from heavier nuclei at this energy.

Recently, ϕ meson production off the nuclei was measured in order to investigate the mass shift of ϕ meson in the nuclear media by using 12 GeV proton beam at KEK-PS ??, where the momenta of ϕ mesons are $1 \sim 3$ GeV/c The phenomenological fitting was applied in the form of A^{α} as the mass number dependence of the production cross section. The parameter α resulted in 1.01 ± 0.09, which means no absorption of ϕ meson in the nucleus [4]. This result is inconsistent with the ϕ-nucleon total cross section of 12 mb deduced in the earlier photo-production if the cross section is independent of the ϕ meson momentum. At SPring-8/LEPS, the similar momentum region at KEK-PS can be available ($1.0 \sim 2.2$ GeV/c). The mass number dependence can be compared to the KEK-PS data. At any rate, we can deduce ϕ-nucleon total cross section from the incoherent photo-production off the nuclei by optical theorem [2] — if we can measure the coherent production from heavier nuclei, the cross section may also be deduced like those at high energies.

Assuming vector dominance model, one can also deduce ϕ-nucleon total cross section from ϕ photo-production off the nucleon. It is quite important to compare those cross sections to understand the nature of ϕ-nucleon interaction. The deduced ϕ-nucleon total cross section itself can be used to check the ϕ-nucleon interaction predicted from various models based on quantum chromodynamics (QCD).

The ϕ meson is regarded as an important probe to study chiral symmetry restoration or the quark gluon plasma (QGP). High energy heavy ion experiments are trying to detect ϕ as well as the KEK experiment. The data of the ϕ-nucleon cross section at low energies is very important for these studies.

The following theme is also measured in this experiment:

- to study the final state interaction or medium effect investigating the ϕ invariant mass spectra in detail,
- to deduce the cross section by using K^+/K^- single production cross section off the nuclei to check the optical theorem,
- to study $\Lambda(1520)$ by detecting K^- and p, and
- to search for K^-A bound state by detecting K^+.

EXPERIMENTAL METHOD AND APPARATUS:

At SPring-8/LEPS, the incoherent process of the ϕ photo-production is dominant because the momentum transfer $|t|$ does not reach the small enough to observe its process due to the small incident photon energy near the threshold of the ϕ photo-production. The incoherent photo-production cross section is given as following equation according to the optical theorem [1].

$$\frac{d\sigma}{dt}(A) = \frac{d\sigma_0}{dt}N(\sigma_1, \sigma_2)$$

where $\frac{d\sigma}{dt}(A)$ is the photo-production cross section off the nuclei, $\frac{d\sigma_0}{dt}$ is that off the nucleon, and $N(\sigma_1, \sigma_2)$ is the effective nucleon number, which can be calculated if the two total cross sections σ_1 between incident particle and nucleon — for photo-production this should be 0 — and σ_2 between scattered particle and nucleon are given. Thus the ϕ-nucleon total cross section can be deduced from the ratio between the photo-production cross section off the nuclei and that off the nucleon.

In this regard, we aim to measure the ϕ photo-production cross section off the several nuclear targets detecting K^+ and K^- pairs (the ϕ photo production off the hydrogen has been already taken during the construction beam time).

The requested experimental apparatus is the standard LEPS detector systems:

- tagger counter (TAG) for tagging the incident photon energy
- dipole magnet, silicon strip detector array (SVTX), and drift chambers for the momentum analysis
- upstream veto scintillator (UP) for excluding e^+e^- pairs converted from photon at upstream of the experimental hutch.
- start scintillator just downstream of the target (ATG) and scitillator hodoscopes for measuring time of flight (TOF)
- aerogel Cherenkov (AC) for excluding e^+e^- pairs converted from photon at target or start counter.

and the Figure 1 shows its schematic view. Trigger logic is following relation.

$$\left[\mathrm{TAG} \otimes \bar{\mathrm{UP}}\right] \otimes \left[\mathrm{ATG} \otimes \bar{\mathrm{AC}} \otimes \mathrm{TOF}(m \geq 1)\right]$$

where TOF ($m \geq 1$) means at least one scintillator of the hodoscopes should be fired.

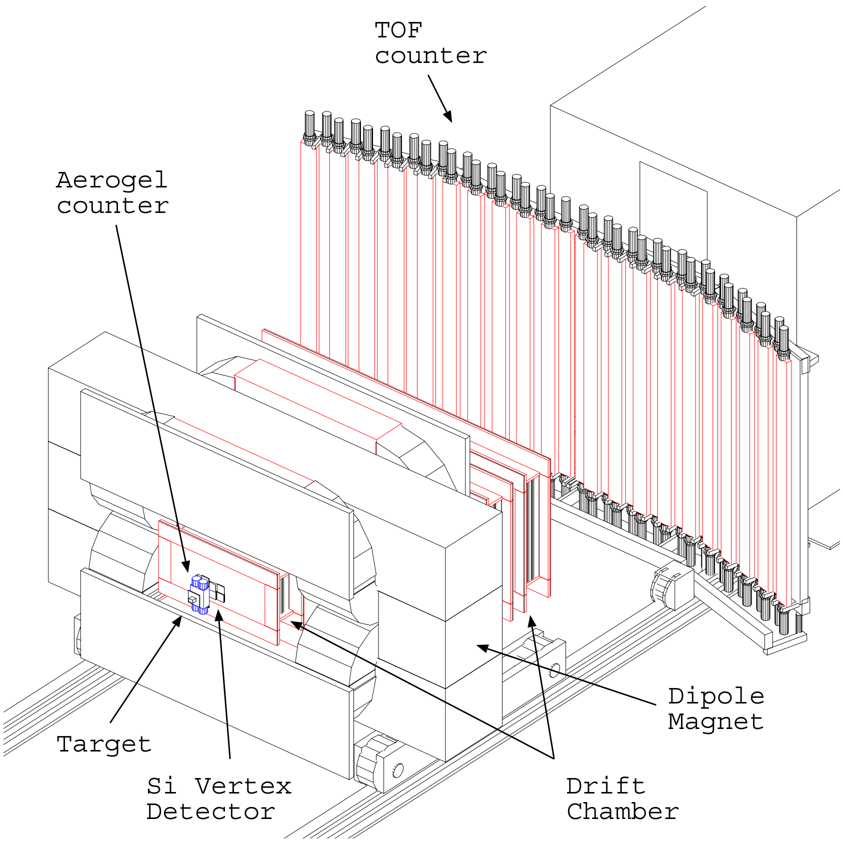

Figure 1: The standard LEPS detector system

ESTIMATION OF THE BEAM TIME REQUESTED:

We have already taken data off hydrogen, carbon, and copper during the construction beam time. Figure 2 shows the invariant mass of K^+K^- pairs and missing mass M_X for the $p(\gamma,\phi)X$ reaction — left part shows those for the hydrogen target and the right part shows those for the carbon.

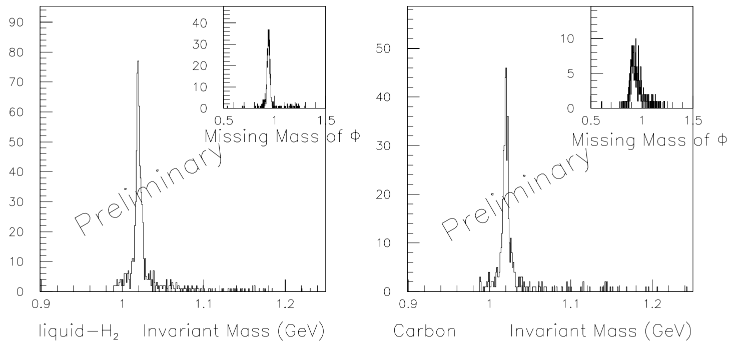

Figure 2: The invariant mass of K^+K^- pairs and the missing mass M_X for $p(\gamma,\phi)X$ for hydrogen and carbon targets.

The ϕ peak are observed in the invariant mass distributions with good resolution and missing mass distributions M_X for $p(\gamma,p)X$ shows the peak at proton mass. We also measured the four momentum of both K^+K^- pairs and the incident γ energy, t-dependent yield can be deduced. Figure 3 shows the preliminary result of the t-dependent yield — normalized by the number of the incident photons and by the target thickness and by the acceptance correction (We don't still know the acceptance very well and we also don't know the event reconstruction ratio or the efficiency of each detectors, thus final results may change largely from this figure).

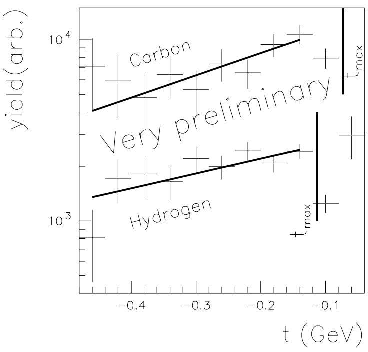

Figure 3: The t-dependent yield of ϕ meson off hydrogen and carbon.

Summing up the yield ratio between $t = -0.45$ and $t = -0.15$, the effective nucleon number is deduced by calculating the ratio between the yield off the nuclei and that off the nucleon. Figure 4 shows the effective nucleon number deduced from the yield off the hydrogen, carbon, and copper targets with both the vertical and horizontal polarizations. The following table shows the statistic of the data taken during the construction beam

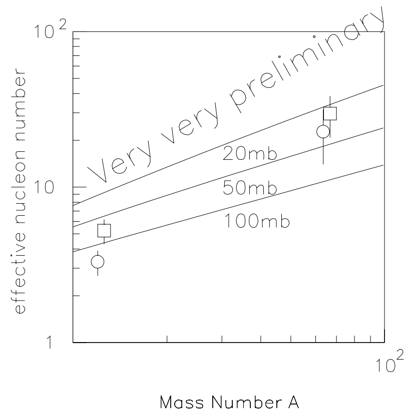

Figure 4: The effective nucleon number for carbon and copper. The circle and box markers show that from vertical and horizontal data, respectively.

time where V and H means that the incident γ is polarized in the vertical and horizontal direction, respectively. We will combine these two polarization direction data into one after the acceptance study is finished.

γ Energy Region	expected (analyzed) number of ϕ mesons	
Target: hydrogen — V 30% / H 23% analyzed		
2.2 ~ 2.4 GeV	V ~1200 / H ~1900	(V 364 / H 443)
2.0 ~ 2.2 GeV	V ~820 / H ~1200	(V 246 / H 277)
1.6 ~ 2.0 GeV	V ~530 / H ~790	(V 159 / H 181)
Target: carbon — V 60% / H 37% analyzed		
2.2 ~ 2.4 GeV	V ~420 / H ~650	(V 250 / H 234)
2.0 ~ 2.2 GeV	V ~210 / H ~290	(V 127 / H 103)
1.6 ~ 2.0 GeV	V ~110 / H ~200	(V 66 / H 71)
Target: copper — 100%analyzed		
2.2 ~ 2.4 GeV	V 15 / H 20	(V 15 / H 20)
2.0 ~ 2.2 GeV	V 11 / H 18	(V 11 / H 18)
1.6 ~ 2.0 GeV	V 8 / H 7	(V 8 / H 7)

We would like to determine the effective nucleon number at three energy regions to investigate the momentum dependent total cross section within ∼6 % error (the excess due to the some resonance might be observed?). The ∼6% error for the effective nucleon number corresponds to the error of ϕ-nucleon cross section as follows:
∼ 20% error for 10mb, ∼ 15% error for 20mb
∼ 6% error for 50mb, ∼ 5% error for 100mb.
To reduce both the statistic and systematic errors, we prefer to take data of four targets — deuteron, carbon, aluminum, and copper —, and ∼1000 ϕ mesons are needed for each target to achieve the ∼6% error in every energy bin (We will decide the energy regions so that the number of ϕ mesons are almost the same in each energy bin and the error of effective nucleon number was estimated from only the statistic error of the yields at this moment). The number of ϕ mesons and corresponding data taking time is written in the following table. In order to take data for deuteron by subtracting the data for carbon

target	number of ϕ mesons	taking time	thickness
deuterized polyethylene (CD_2)	3200	33 shifts	60.0 mm
carbon (C)	600(+∼1800)	6 shifts	33.0 mm
aluminum (Al)	1000	18 shifts	20.0 mm
copper (Cu)	930(+∼70)	45 shifts	3.0 mm
Sum		102 shifts	

from that for deuterized polyehylene, extra ϕ mesons are needed as for the carbon and deuterized polyethylene. But main purpose of taking data for the deuteron is to investigate the difference between ϕ photo-production cross section off the proton and off the neutron, thus we set goal of the statistical error for deuteron to ∼9% in the whole energy reigon. The data taking time was estimated by using the previous one for carbon assuming the cross section should be the form of $A^{2/3}$. The assumed thickness of each target is inserted in the same table.

EXPERIMENTAL SCHEDULE:

In order to reduce the systematic error, we would like to take data as follows in one period, in which the filling pattern of the SPring-8 storage ring is the same.

33% deuterized polyethylene
6% carbon
18% aluminum
44% copper

REQUEST FOR THE BEAM CONDITION AND EXPERIMENTAL EQUIPMENT:

As for the beam conditions, both vertical and horizontal polarization direction are needed to check the systematical errors originated from different acceptances, and high and stable intensity beam is preferable as possible as SPring-8 electron storage ring condtion and LEPS DAQ system can keep. As for the experimental equipment, standard setup is needed. The travel budget for the collaborators who belongs to the Kyoto University and the cost for preparing the nuclear targets are supported by Experimental Nuclear and Hadronic Laboratory, Kyoto Univesity. Travel budget for the other collaborators and LEPS supporting staff are needed.

EQUIPMENT PROVIDED BY THE EXPERIMENTERS:

We will prepare the following targets as the nuclei, where X_0 is the radiation length.

target	thickness
deuterized polyethylene (CD_2)	60.0mm ($\sim 0.15X_0$)
carbon (C)	33.0 mm ($\sim 0.18X_0$)
alminum (Al)	20.0 mm ($\sim 0.20X_0$)
copper (Cu)	3.0 mm ($\sim 0.20X_0$)

References

[1] G. McClellan *et al.*, Phys. Rev. Lett. 26, 1593 (1971) and references therein.

[2] K.S. Kölbig and B. Margolis, Nucl. Phys. B6, 85 (1968), B. Marogolis, Phys. Lett. 26B, 524(1968), B. Margolis, Nucl. Phys. B4, 433 (1968), and references therein.

[3] KEK-PS E325 proposal, 1994, S. Yokkaichi*et al.*, Proceedings of Quark Matter 97: Nucl. Phys. A368, 435c (1998), and references threrein.

[4] M. Ishino, Memories of the Faculty of Science, Kyoto University, Science of Physics, Astrrophysics, Geographics and Chemistry, Vol. 42-1 1 (2001), and his doctor thesis.

[5] T.H. Bauer *et al.*, Rev. Mod. Phys. 50, 261 (1978), and references therein.

[6] G. von Bochman, B. Margolis and C.L. Tang, Phys. Lett. 24, 483 (1970).