Backward ϕ photo-production from C and Cu targets at E_γ = 1.5 - 2.4 GeV

Takahiro Sawada, Institute of Physics, Academia Sinica, Taiwan
on behalf of the LEPS Collaboration

Hadron in Nucleus - Kyoto (Japan)
Oct 31st – Nov 2nd, 2013

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Not Only

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ϕ-meson Properties in Nuclear Medium

The way to approach to observe the in-medium ϕ properties

- **Mass-Spectrum Measurement**
  - $l^+ l^-$ decay channel
    - Small FSI
    - Small branching ratio (~10^{-4})
    - Many backgrounds.

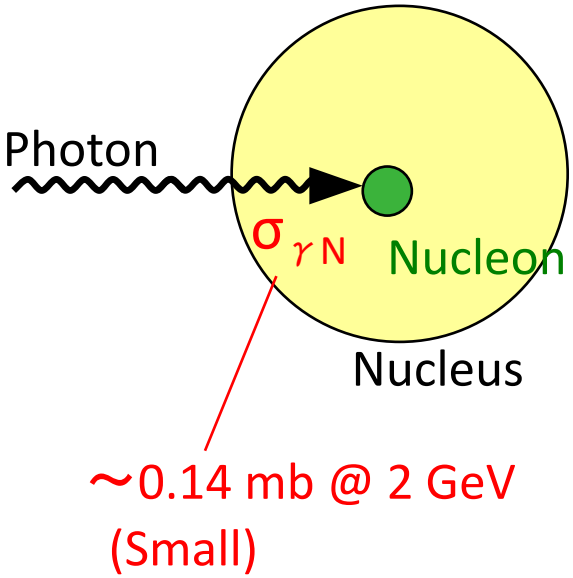
Chiral Symmetry Restoration

- **Target Mass Number (*A*) dependence Measurement**
  - $K^+ K^-$ decay channel
    - Large branching ratio (~50%)
    - Cancellation of Systematic Errors

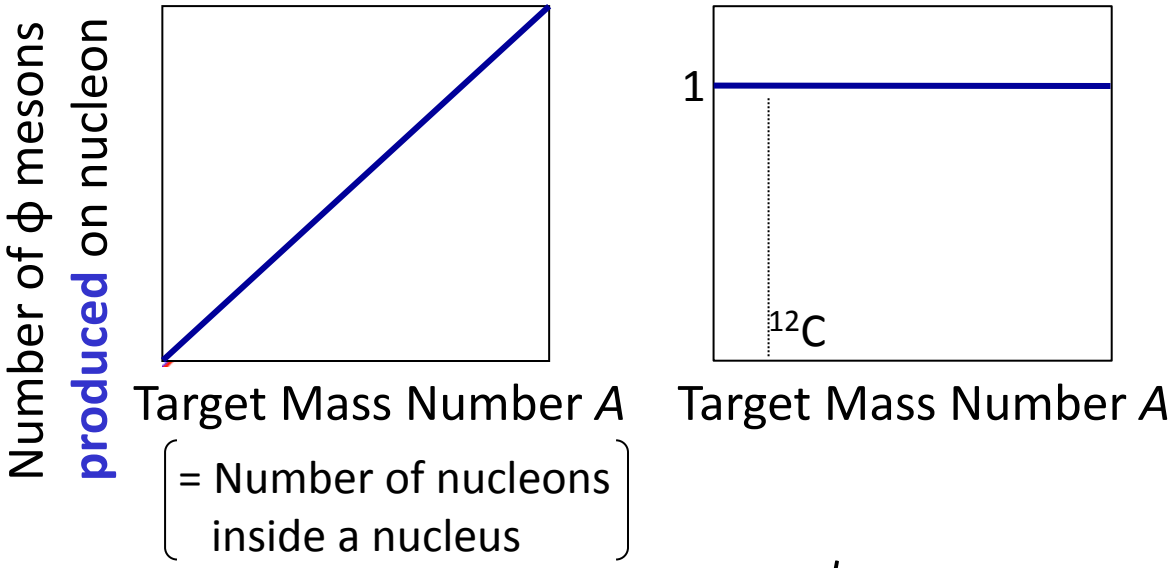
ϕ-Nucleon interaction

A-dependence Measurement

Incoherent ϕ photo-**production**



Normalization



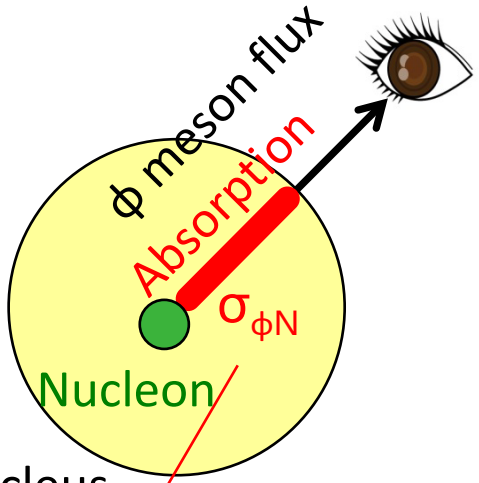
$$N_A^{\phi} \propto A^{\alpha}$$

$$\alpha \sim 1$$

$$\frac{N_A^{\phi} / A}{N_C^{\phi} / A_C} \sim 1$$

A-dependence Measurement

Propagation & Observation

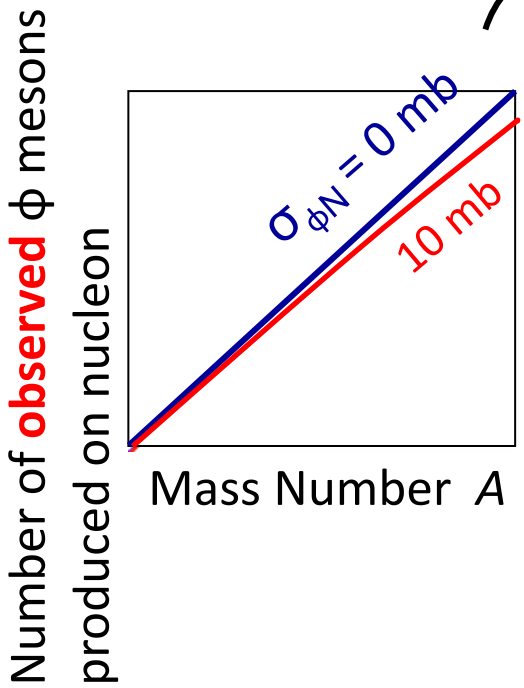


Theoretical Calculation (only in free space)

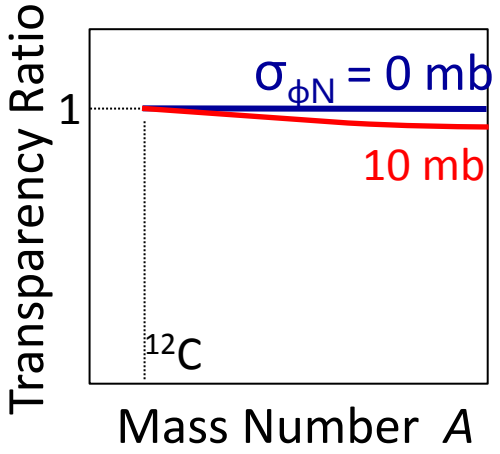
~10 mb (OZI suppression)

VMD model : 8.2 ± 0.5 mb

Quark model : 13.0 ± 1.5 mb



Normalization



H.J. Lipkin, Phys. Rev. Lett. 16, 1015 (1966).
H.-J. Behrend et al., Phys. Lett. 56 B, 408 (1975).

Observed Result ⇔ $\sigma_{\phi N}$

Glauber Approximation

$$Transparency\ Ratio = \frac{R_{Cu}^{\phi}/A_{Cu}}{R_{C}^{\phi}/A_{C}} = \frac{N_{Cu}^{eff}/A_{Cu}}{N_{C}^{eff}/A_{C}}$$

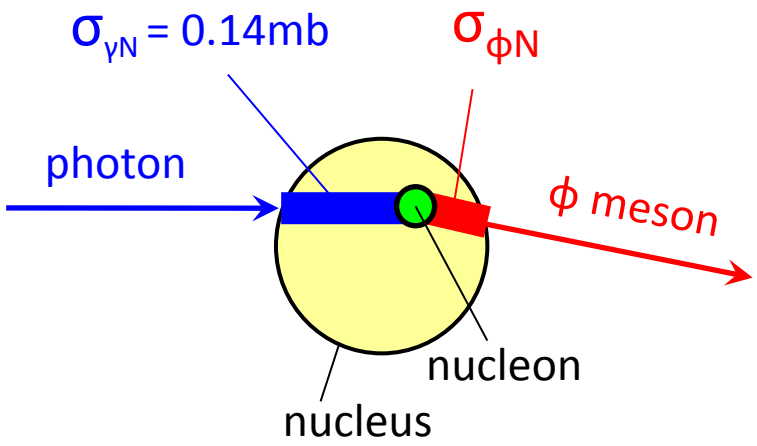
here,

$$N_A^{eff} = \int d^2b\, dz\, \rho(b,z)\, S_\gamma(b,z)\, S_\phi(b,z,\theta,\phi)$$

$$S_\gamma(b,z) = \exp\left[-\sigma_{\gamma N}\int_{-\infty}^{z} dz'\rho_A(b,z')\right] = e^{-\sigma_{\gamma N}T_Z(b)}$$

$$S_\phi(b,z,\theta,\phi) = \frac{1}{2\pi}\exp\left[-\sigma_\phi \oint d\xi\, \rho\left(\left|\mathbf{r}_\xi\right|\right)\right]$$

$$r_\xi^2 = \left(b+\xi\cos\phi\sin\theta\right)^2 + \left(\xi\sin\phi\sin\theta\right)^2 + \left(z+\xi\cos\theta\right)^2$$



Nuclear density distribution: Woods-Saxon

$$\rho_A(r) = \frac{\rho_0}{1+\exp\left[(r-R)/d\right]},\quad R = 1.28A^{1/3} - 0.76 + 0.8A^{-1/3}\ \text{fm},\quad d = \sqrt{3}/\pi\ \text{fm}$$

Connect two variables

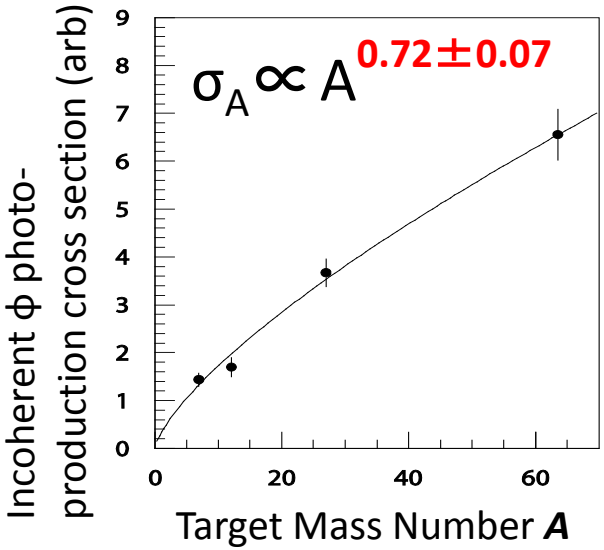
Transparency Ratio ⇔ $\sigma_{\phi N}$

A-dependence @ LEPS, CLAS

SPring-8/LEPS

T. Ishikawa et al. Phys.Lett. B608 (2005) 215-222

photo-production at E_γ = 1.5 – 2.4 GeV
$\phi \rightarrow K^+ K^-$
$< p_\phi > =$ 1.8 GeV/c .
Li, C, Al, and Cu targets.

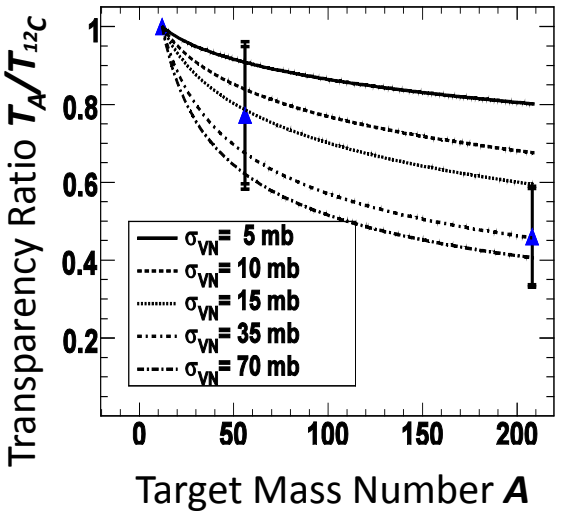


$\sigma_{\phi N} = 35^{+17}_{-11}$ mb

JLab/CLAS

M. H. Wood et al. Phys.Rev.Lett. 105 (2010) 112301

photo-production at E_γ < 3.8 GeV
$\phi \rightarrow e^+ e^-$
$< p_\phi > =$ 2 GeV/c .
(^{2}H), C, Ti, Fe, and Pb targets.



$\sigma_{\phi N} = 16$ -70 mb

$\sigma_{\phi N}$

Theoretical Calculation (in free space)

VMD model : 8.2 ± 0.5 mb

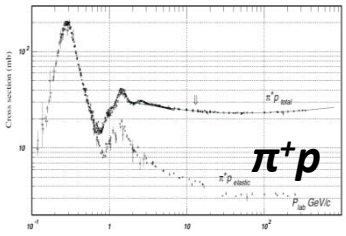
Quark model : 13.0 ± 1.5 mb

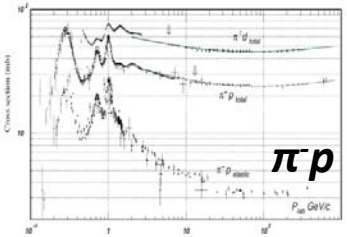
H.J. Lipkin, Phys. Rev. Lett. 16, 1015 (1966).
H.-J. Behrend et al., Phys. Lett. 56 B, 408 (1975).

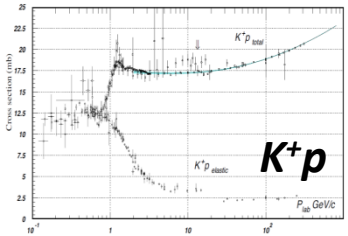
Analogy to other mesons (K^+ , K^- , $\pi^\pm$)

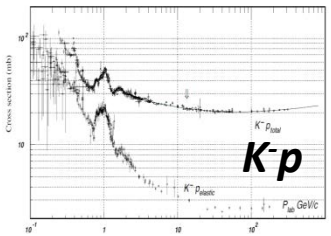
- OZI suppression.
- ϕ-N resonance has not been reported.
- Total hadronic cross section at a few GeV region

$$\sigma_{total}^{ab} = Z^{ab} + B\ \ln^2(s/s_0) + \cdots$$









?
ϕN

- At 2 GeV/c

$\sigma_{\phi N}$ < σ_{K^+N} < σ_{K^-N} , σ_{π^+N} , σ_{π^-N}

? 18 mb 30 mb 30mb 35mb

A-dependence @ ANKE-COSY

ANKE-COSY

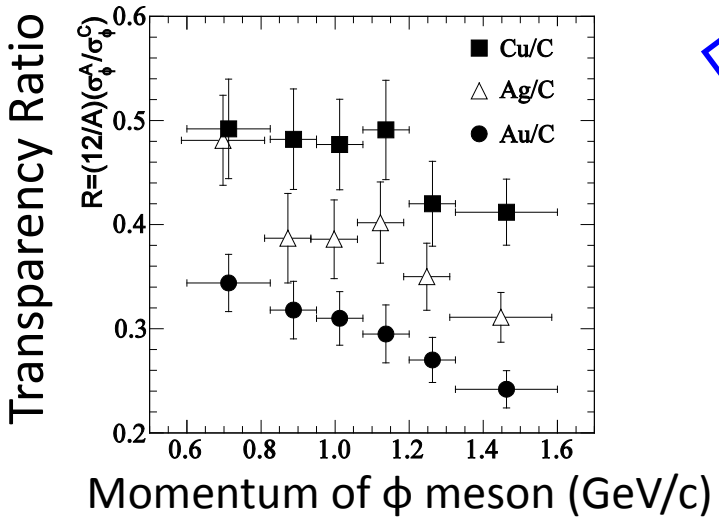
M. Hartmann et al, Phys.Rev. C85 (2012) 035206

2.83 GeV **proton beam**

$\phi \rightarrow K^+ K^-$

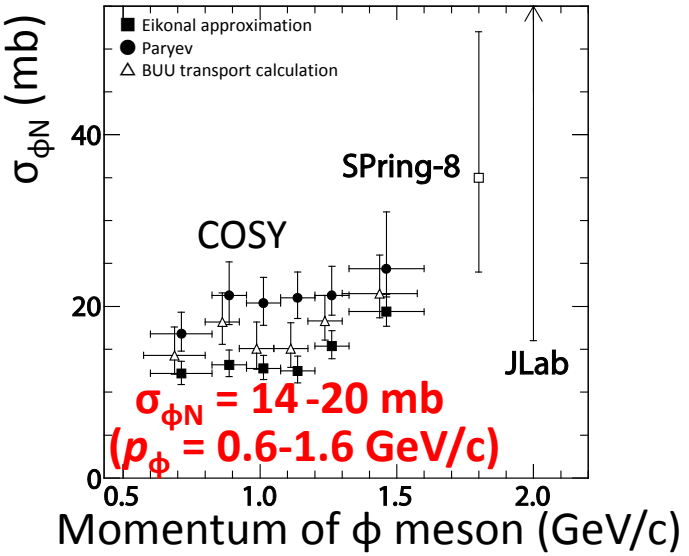
p_ϕ = 0.6 - 1.6 GeV/c

C, Cu, Ag, and Au targets



Transparency Ratio decreases with ϕ momentum.

Extraction



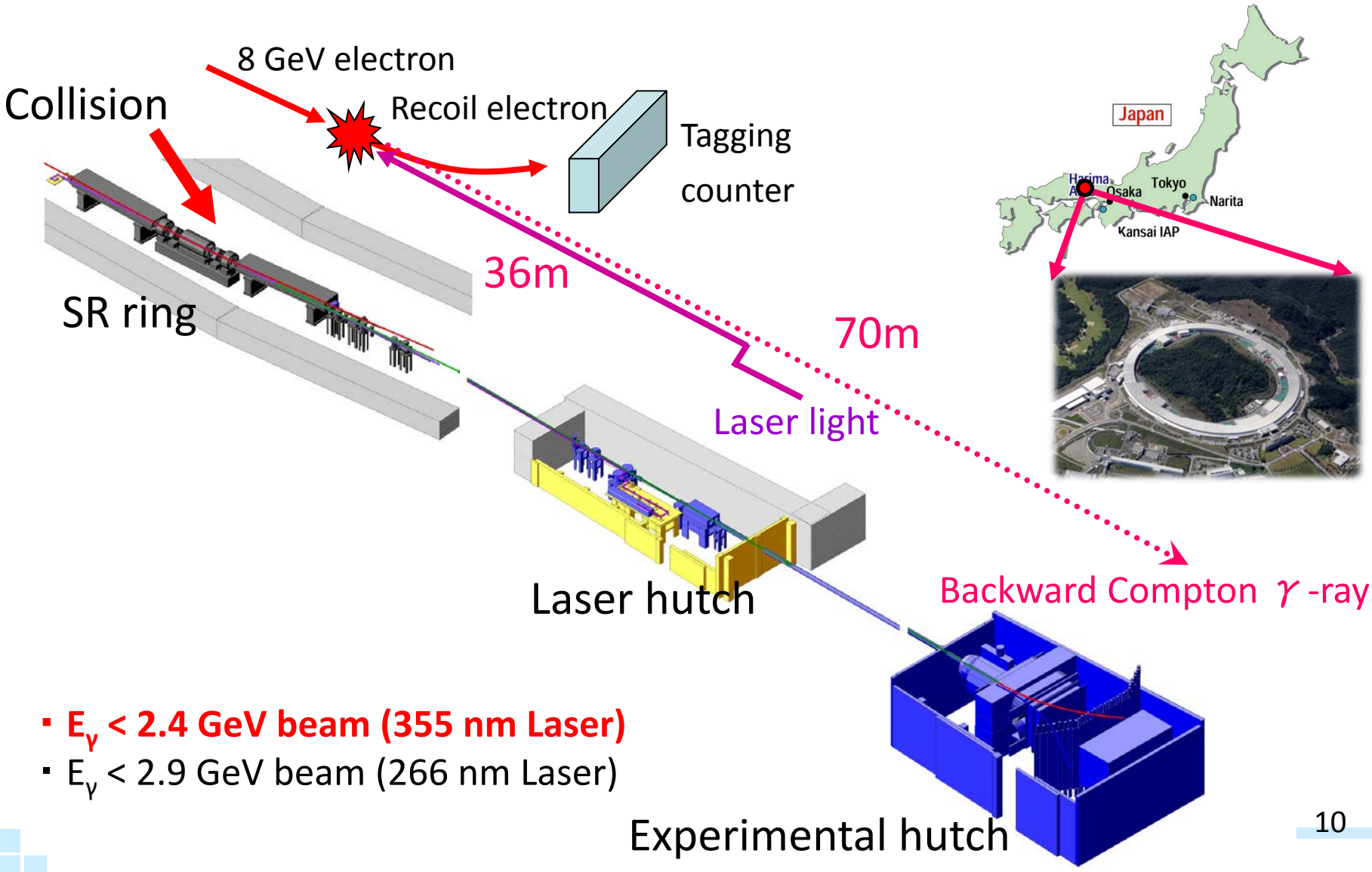
ϕ-meson

at slow speed ↕ at fast speed

Transparent (not modified) ↕ Absorbed (modified) !?

The verification experiment using photon beam is desired !!

LEPS facility @ SPring-8



- **E_γ < 2.4 GeV beam (355 nm Laser)**
- E_γ < 2.9 GeV beam (266 nm Laser)

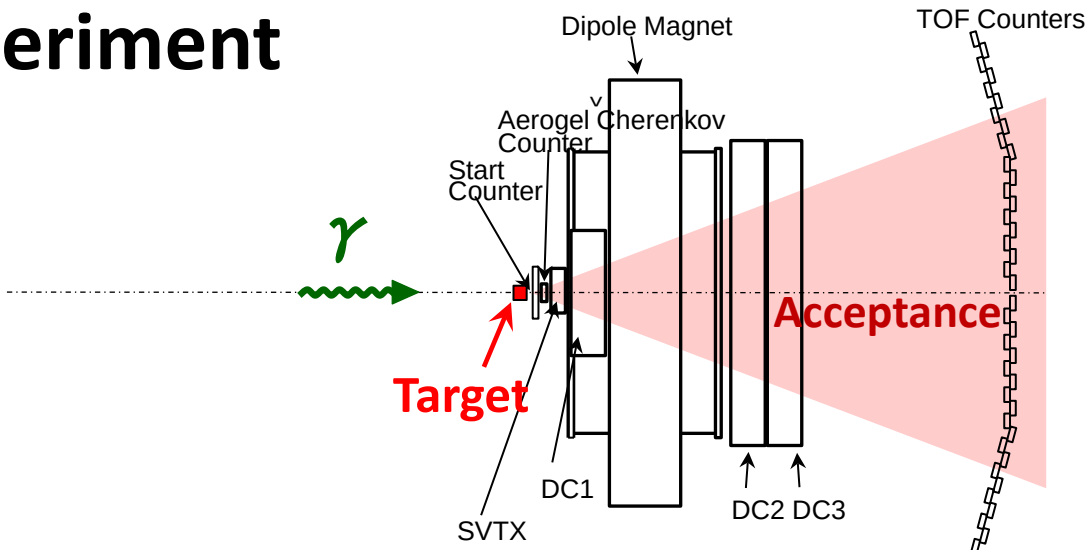
Experimental Apparatus

Previous Experiment

Acceptance

Hori ±20°

Vert ±10°

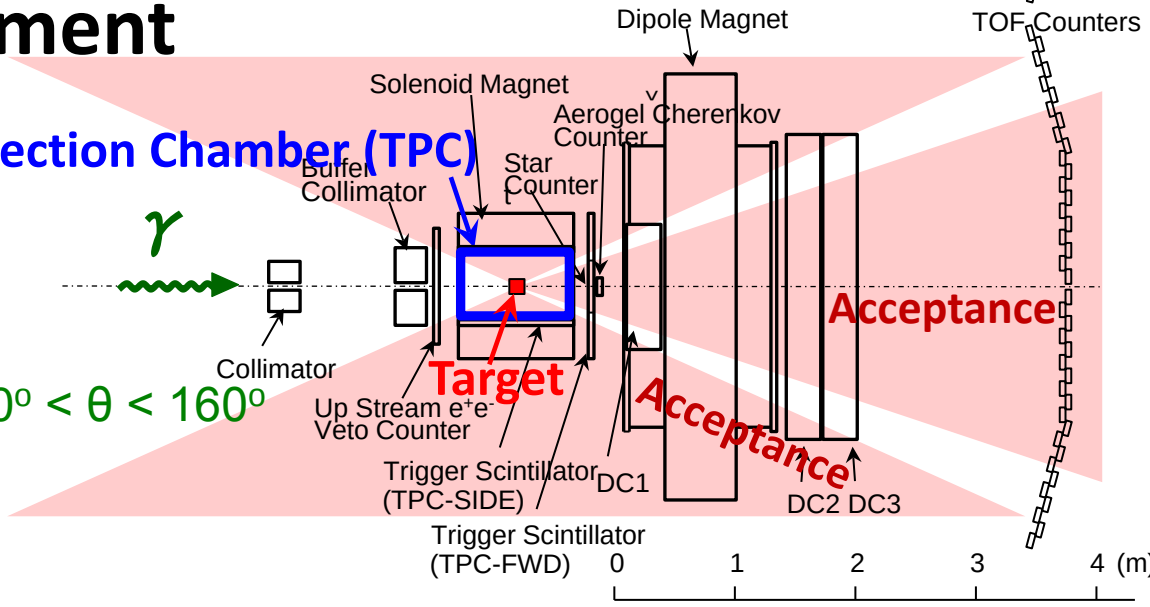


This Experiment

Time Projection Chamber (TPC)

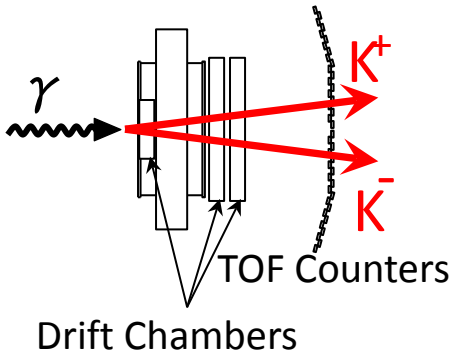
Acceptance

Forward + 20° < θ < 160°

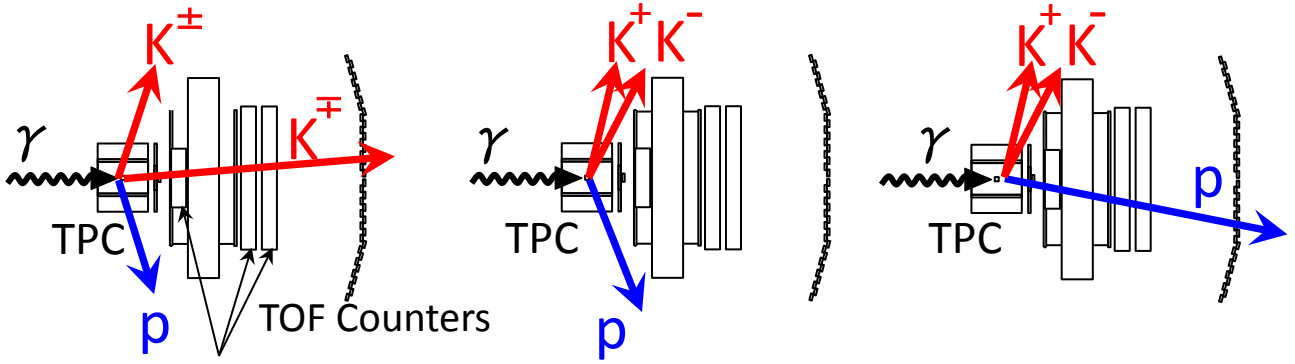


Detection Modes for ϕ mesons

Previous Experiment



This Experiment (+ TPC)



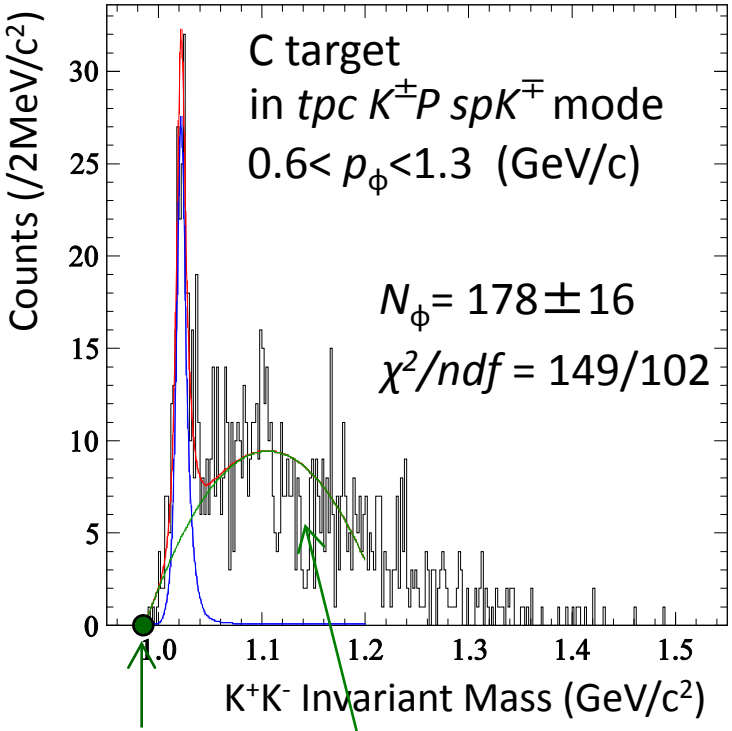
Fast ← Momentum of ϕ meson in LAB system → Slow

Forward ← Angle of ϕ meson in CM system → Backward

ϕ Experiment with Nuclear Targets @Spring-8/LEPS

	Previous experiment	This experiment
Period	Nov. in 2001	Sep.- Dec. in 2004
Beam	1.5-2.4 GeV photons	
Targets	Li, C, Al, and Cu	C, Cu, (and CH_2)
Reaction	$\phi \rightarrow K^+ K^-$	
Main Detectors	Forward spectrometer	Forward spectrometer + TPC
ϕ momentum	p_ϕ = 1.0-2.2 GeV/c (Ave. 1.8 GeV/c, 1-Bin)	p_ϕ = 0.3-2.0 GeV/c (4-Bins)

$K^+ K^-$ Invariant Mass



— DATA

— Fit result

— $\phi \rightarrow K^+K^-$ (determined by the MC simulation)

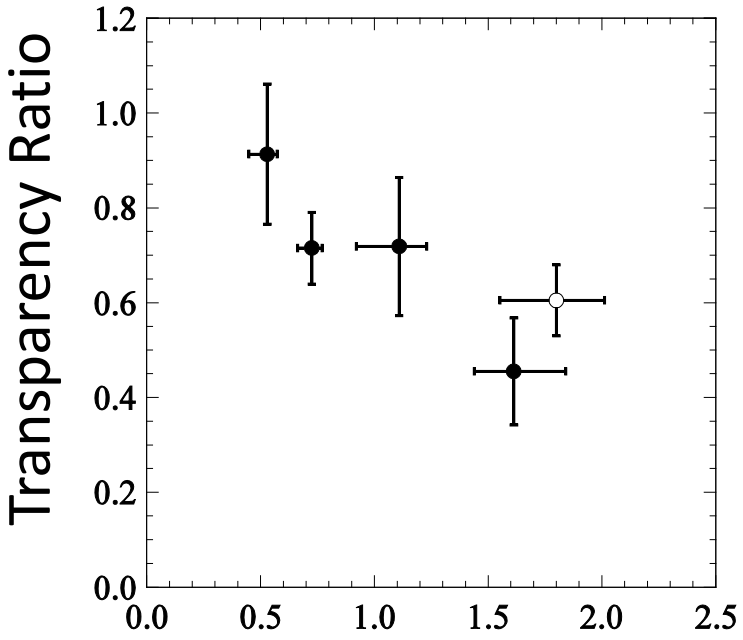
— background (2nd-order polynomial)

Fit range ;
from $2m_{K^\pm}$(0.987) to 1.2 GeV/c²

Summary Table

Detection Mode	p_ϕ [GeV/c]	C	Cu
$tpcK^+K^-P$	0.3 – 0.6	125 ± 14	87 ± 11
	0.6 – 0.8	405 ± 26	188 ± 17
$tpcK^+K^-spP$	0.3 – 0.6	28 ± 7	13 ± 4
	0.6 – 0.8	48 ± 9	13 ± 5
$tpcK^{\pm}PspK^{\mp}$	0.6 – 1.3	178 ± 16	49 ± 9
	1.3 – 2.0	250 ± 21	41 ± 10

Transparency Ratio



$$T = \frac{R^{\phi}_{Cu}/A_{Cu}}{R^{\phi}_{C}/A_{C}}$$

Here, the production rate of ϕ mesons

$$R^{\phi}_{A} = \frac{N^{\phi}_{A}}{N^{beam}_{A}\, N^{nuclei}_{A}\, \eta^{att}_{A}\, \eta^{geo}_{A}\, BR}$$

- N^{ϕ} : Number of observed ϕ mesons,
- N^{beam} : Number of beam photons on target,
- N^{nuclei} : Number of target nuclei in a unit area,
- η^{att} : Attenuation factor of the photon flux in the target material,
- η^{geo} : Geometrical acceptance,
- BR : Branching ratio of the $\phi \to K^{+}K^{-}$ process

● This experiment (C and Cu)

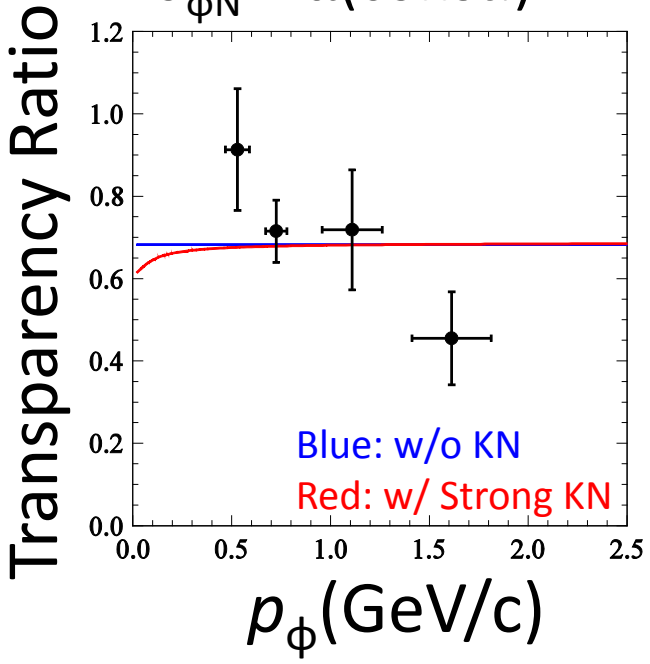
○ Previous experiment (Li, C, Al, and Cu)

Transparency ratio decreases with ϕ momentum

Same tendency as the result of COSY/ANKE collaboration

$\sigma_{\phi N}$

$\sigma_{\phi N} = \alpha$(const.)



using Glauber multiple scattering theory

$$\sigma_{\phi N} = 21.7\ ^{+8.7}_{-6.2}\ \text{mb}$$

$\chi^2/\text{ndf} = 6.95 / 3$

(χ^2 prob.= 7 %)

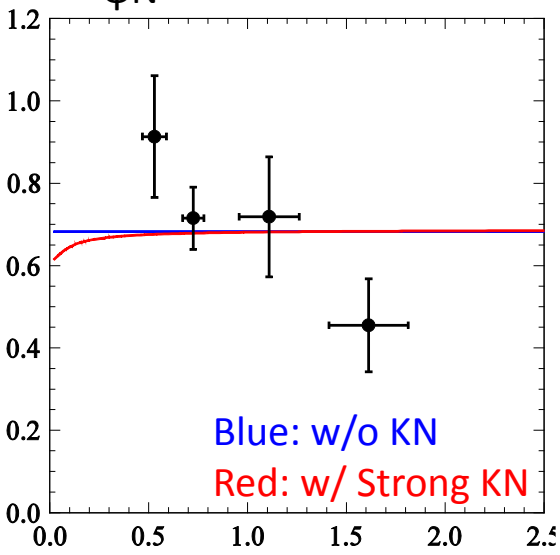
This agrees with the result in previous experiment ($35\ ^{+17}_{-11}$ mb) within the statistical errors.

$\sigma_{\phi N}$ (Momentum Dependent ?)

Assuming that $\sigma_{\phi N}$ has the momentum dependency

Transparency Ratio

$\sigma_{\phi N} = \alpha$(const.)

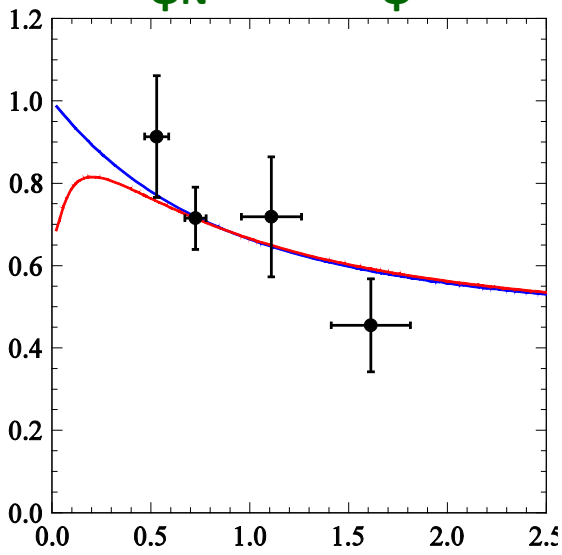


p_ϕ(GeV/c)

χ^2/ndf = 6.95 / 3

(χ^2 prob.= 7 %)

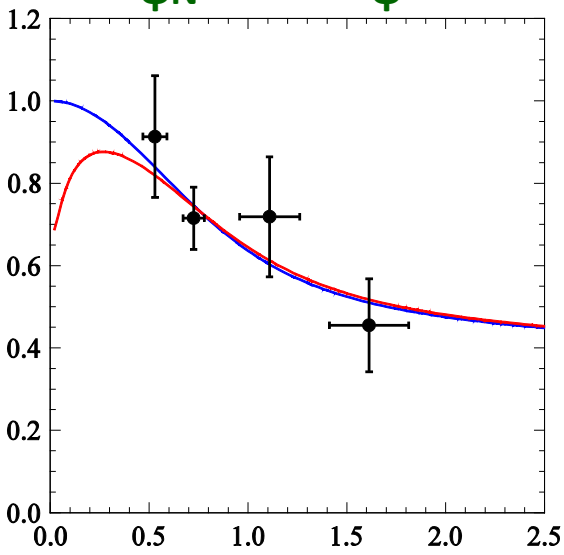
$\sigma_{\phi N} = \alpha \cdot p_\phi$



χ^2/ndf = 2.77 / 3

(χ^2 prob. = 43%)

$\sigma_{\phi N} = \alpha \cdot p_\phi^2$



χ^2/ndf = 1.32 / 3

(χ^2 prob. = 72 %)

More Appropriate

$\sigma_{\phi N}$ (Momentum Dependent ?)

$\alpha = 27.2\ ^{+13.5}_{-9.2}$ mb/(GeV/c)^2

At lower p_ϕ (0.5 GeV/c)

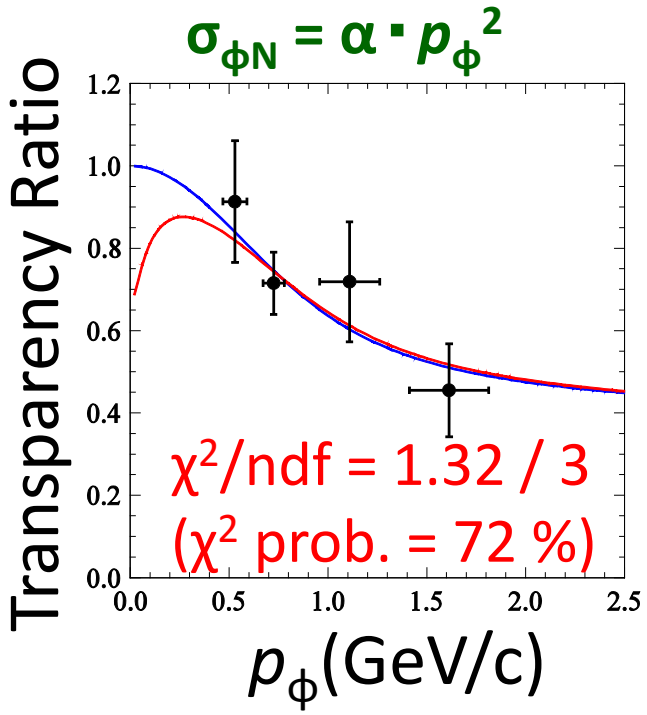
$\sigma_{\phi N} = 6.8\ ^{+3.4}_{-2.3}$ mb

Consistent with the theoretically predicted value in free space.

At higher p_ϕ (1.8 GeV/c)

$\sigma_{\phi N} = 88.1\ ^{+43.7}_{-29.8}$ mb

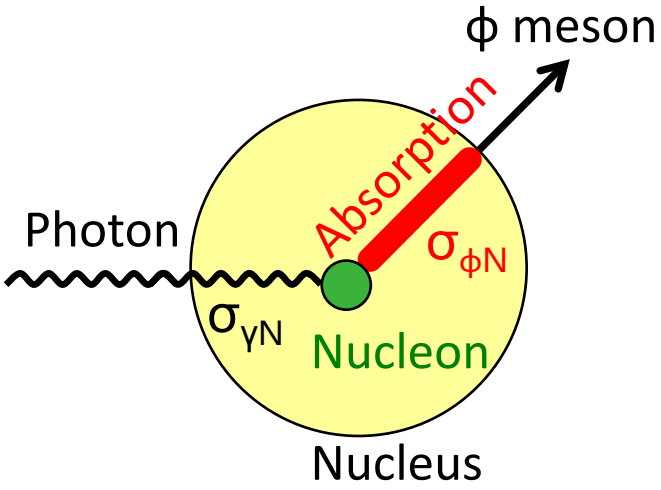
Unexplainable !!!



This suggests that

the cause of the transparency ratio reduction at higher p_ϕ is not the ϕ-*N* interaction.

Discussion



- Production

  The number of ϕ-mesons produced on nucleon is (almost) proportional to the target mass number *A*.

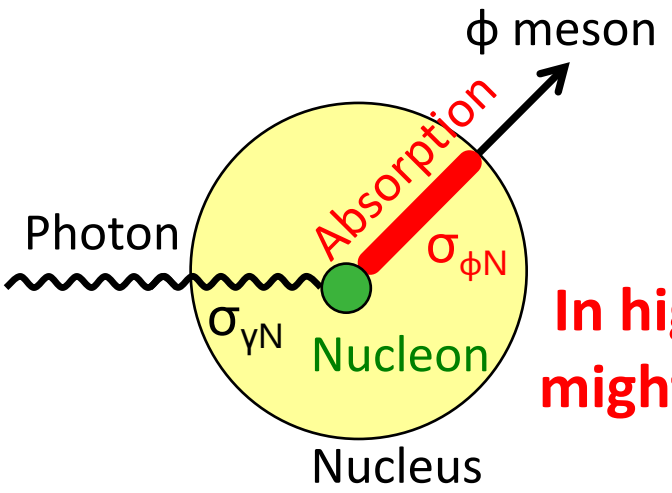
- Propagation

  The flux of ϕ-mesons is decreased by the $\sigma_{\phi N}$.

  ⇨ **Unexplainable**

  ⇧ Measured

Discussion



- Production

~~The number of ϕ mesons produced on nucleon is (almost) proportional to the target mass number *A*.~~

In higher p_{ϕ}, (= Diffractive) ϕ photo-production might have a strong *A*-dependence.

- ~~Propagation~~

~~The flux of ϕ mesons is decreased by the $\sigma_{\phi N}$.~~ ⇨ **Unexplainable**

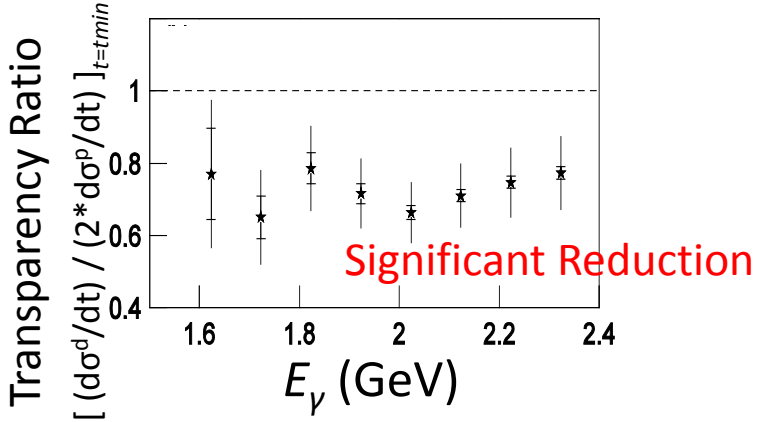
⇧ Measured

Related(?) Topic

ϕ photo-production from the deuteron target

W.C. Chang et al. Phys.Lett., B684:6–10, 2010.

Transparency ratio at forward angles:

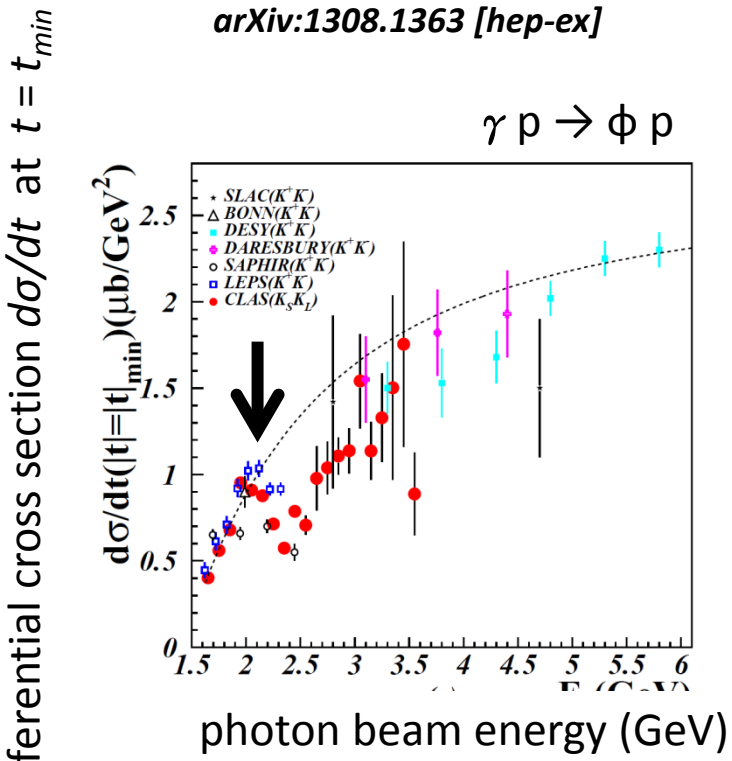


the nuclear medium effect is minimal since the deuteron is composed of a loosely bound proton and neutron

some effect other than nuclear density at forward angles ?

ϕ photo-production on proton target

arXiv:1308.1363 [hep-ex]



Summary

- We have confirmed that the transparency ratio decreases with p_ϕ.
- The reduction of the transparency ratio shown in the high p_ϕ region suggests that
  - ~~$\sigma_{\phi N}$ increases as p_ϕ^2.~~
  - a diffractive ϕ photo-production might have a strong *A*- dependence.

For further study

- Measurement of the **absolute** cross section for each target (not the "**ratio**")
- Improvement of the statistical precision.
- Data-taking with many kinds of target nuclei.
- Measurement at higher p_ϕ .