MENU2010: 12th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon
May 31-June 4, 2010, College of William and Mary, Williamsburg, Virginia

Measurement of Incoherent ϕ-Meson Photo-Production from Deuterons

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on behalf of LEPS Collaboration

- **Introduction**
- **Incoherent ϕ-meson production from deuterons:**
  - **Differential cross section**
  - **Nuclear transparency ratio**
  - **Decay asymmetry**
- **Summary**

Reference: W.C. Chang et al. (LEPS Collaboration), Phys. Lett. B 684: 6-10 (2010)

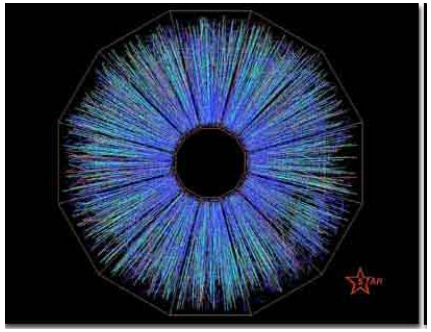
Restoration of Chiral Symmetry

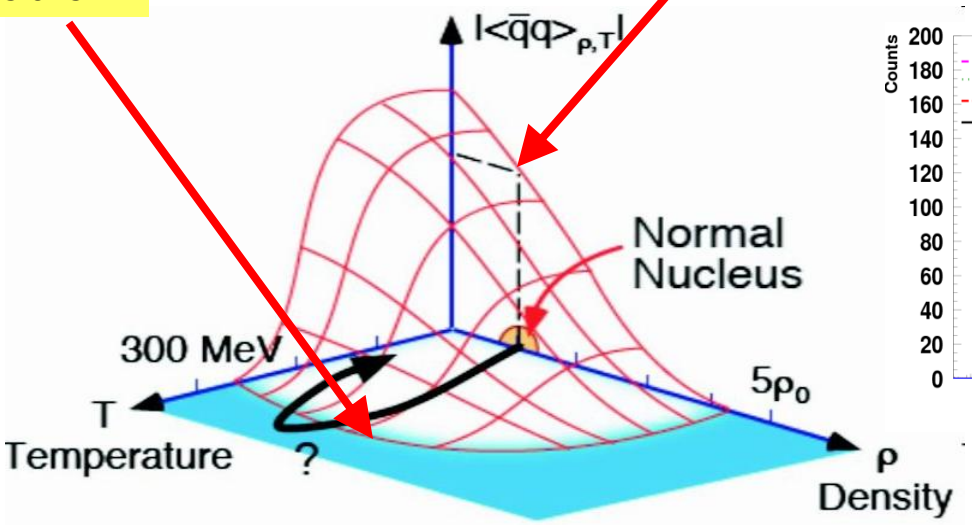
Hadronic properties depend on the hadronic vacuum $<0|q\bar{q}|0>$
$<0|q\bar{q}|0>$ can change with T (temperature) and ρ (density).
As $<0|q\bar{q}|0>$ goes to zero, hadron masses go to zero.

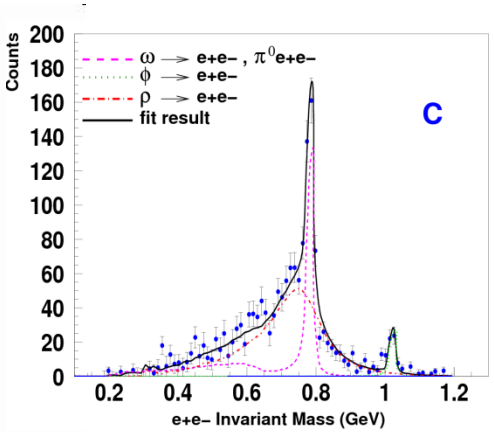
How to measure the modifications?

Light vector meson in a nucleus

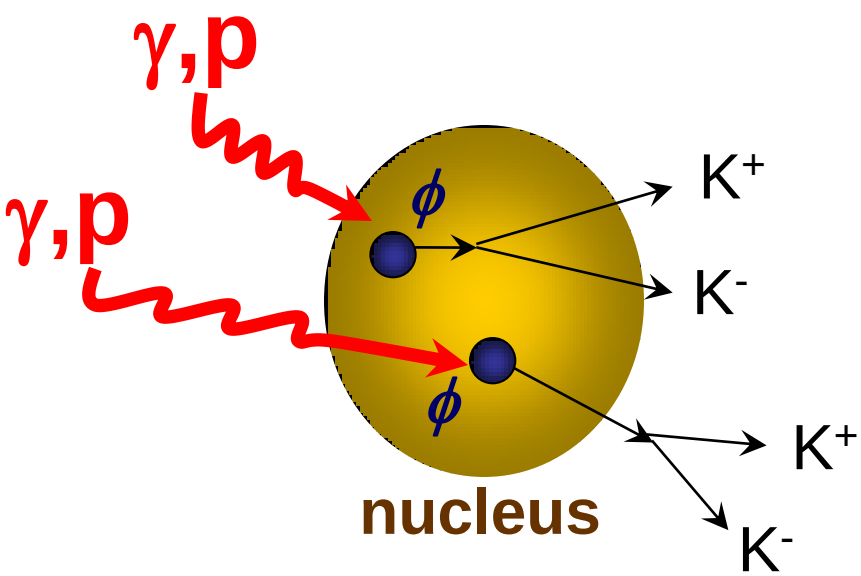
Relativistic Heavy Ion Collisions





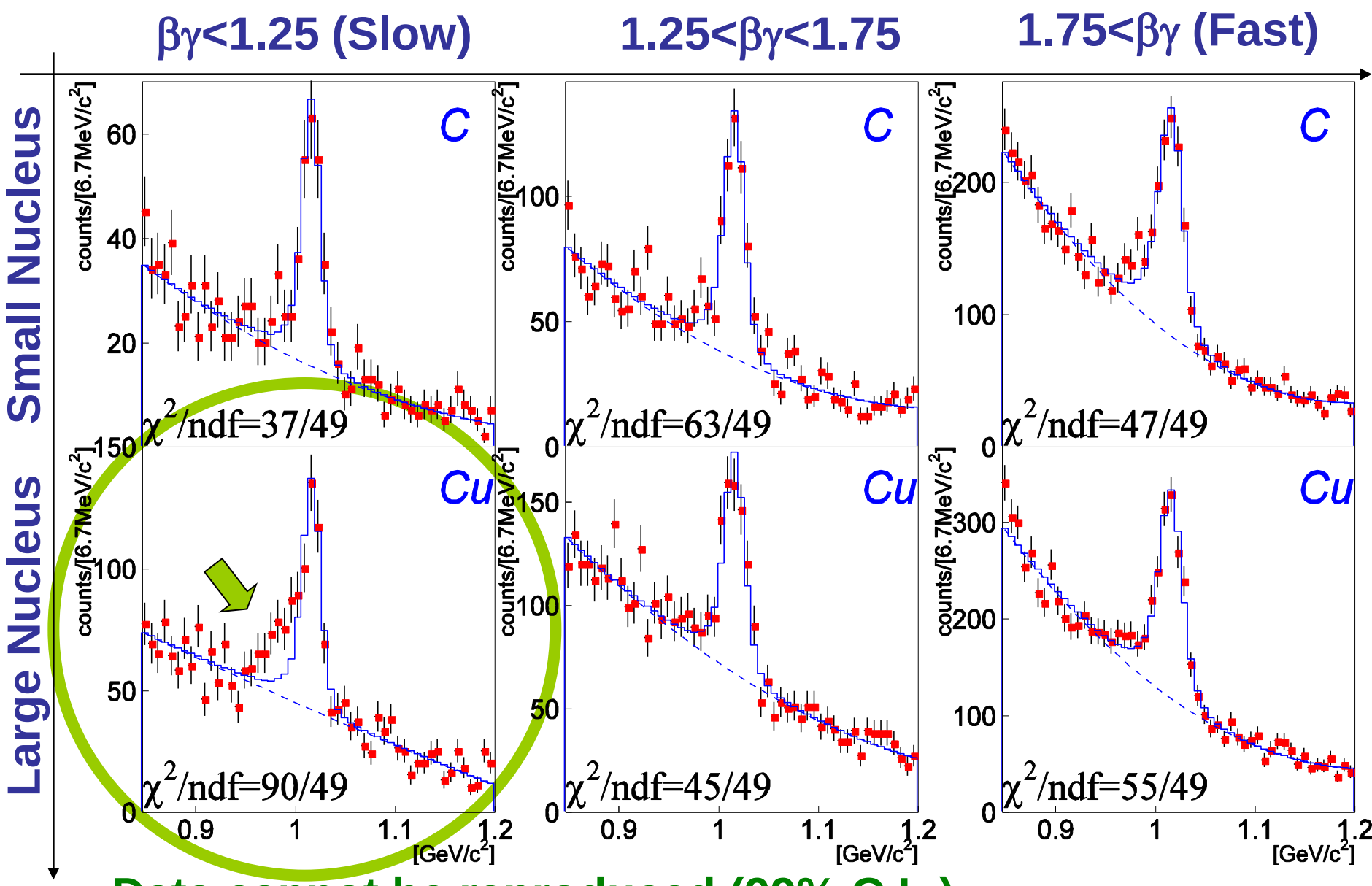


ϕ(1020)-meson as a Probe of Nuclear Medium



- Advantage:
  - Sharp resonance with a narrow width.
- Disadvantage:
  - Long lifetime: mostly decays outside the nuclear medium.
  - Produced with high momentum. Kinematical cuts to isolate small-momentum events reduce poor statistics
  - Strong KN interaction leads to distortion in K+K- distribution.

KEK-E325 p+A (Phys.Rev.Lett.98:042501, 2007) : Invariant Mass $\phi \rightarrow e^+e^-$ Distribution



Data cannot be reproduced (99% C.L.)

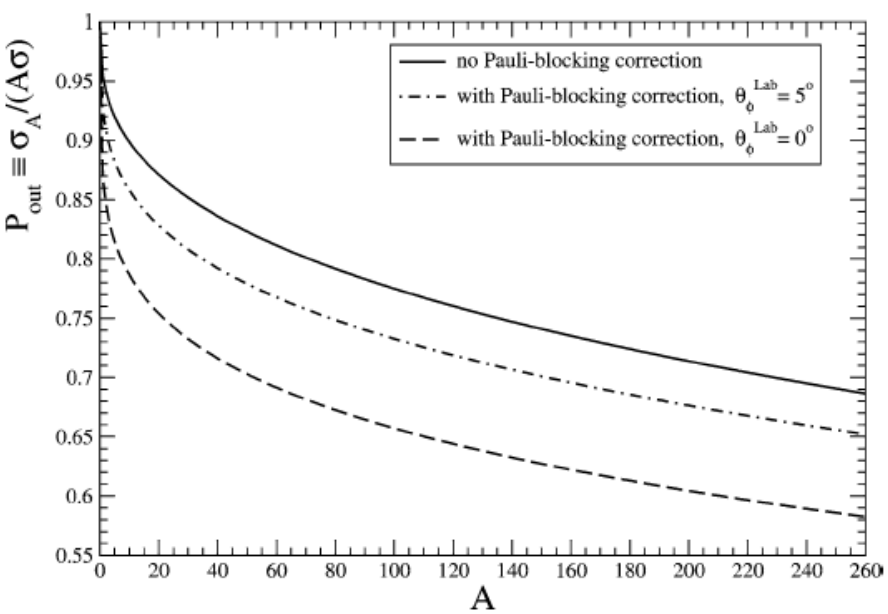
Mass dependence of inclusive nuclear ϕ photoproduction

D. Cabrera et al., Nuclear Physics A 733 (2004) 130

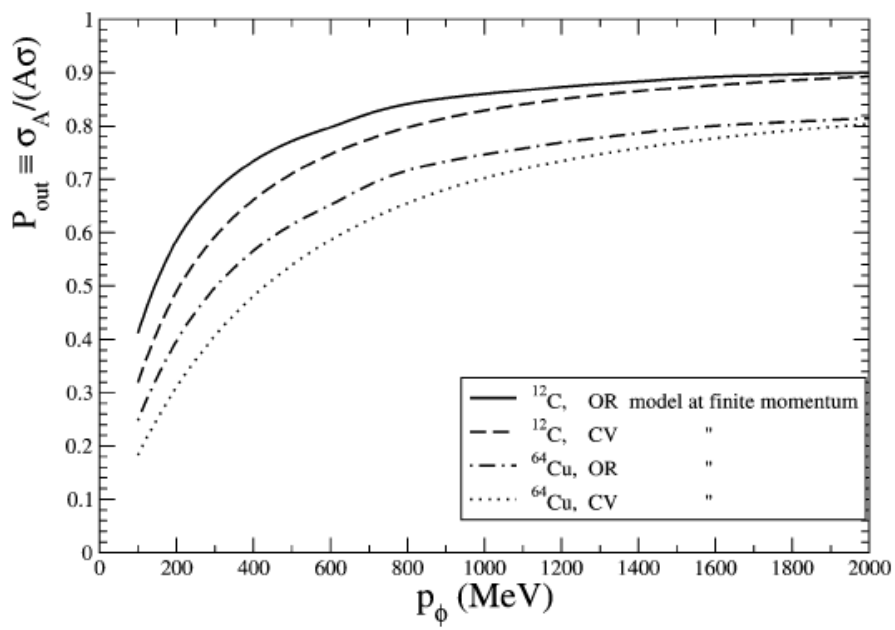
- Proposal: observation of loss of ϕ flux due to nuclear density effects.
- A-dependence of ϕ flux can be related to the ϕ decay width in the nuclear medium.

$$\text{Survial Probability } P_{out} \equiv \frac{\sigma_A}{A * \sigma_p}$$

Nuclear density (ρ) dependence

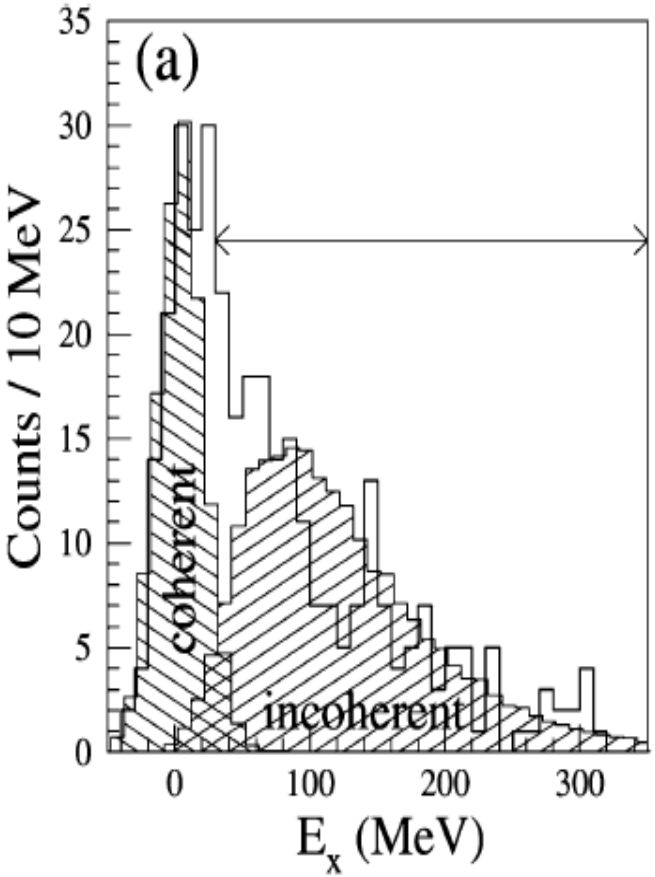


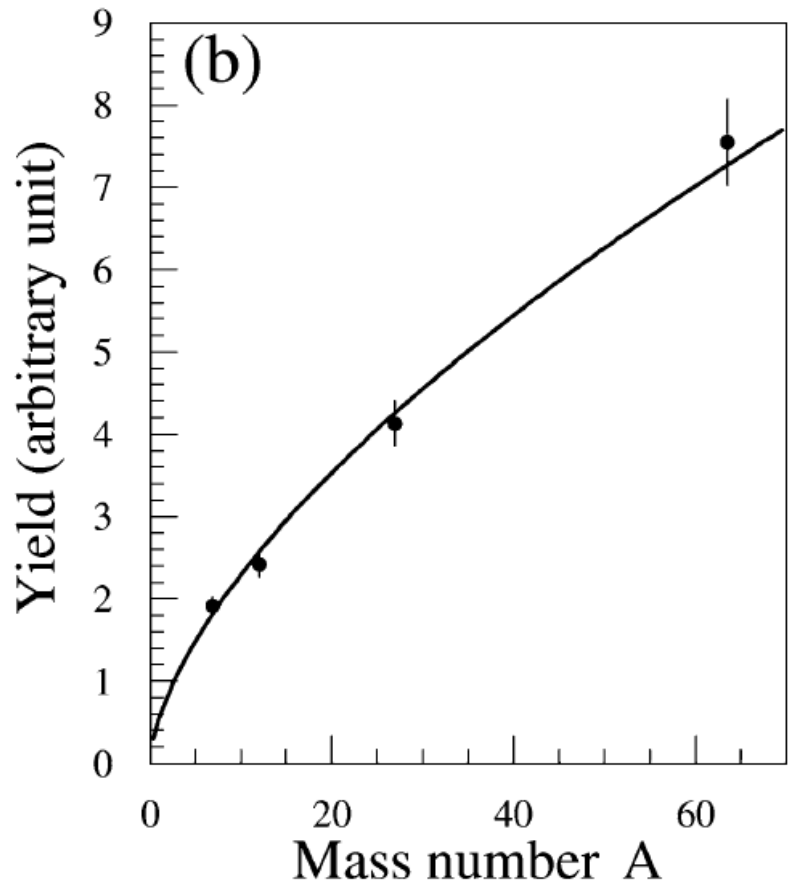
Momentum (p) dependence



LEPS $\gamma A \rightarrow \phi X$

T. Ishikawa et al. (LEPS Collaboration) , Phys. Lett. B 608 (2005) 215–222





VMD calculation from $\gamma p \rightarrow \phi p$: $\sigma_{\phi p}$=12-13 mb

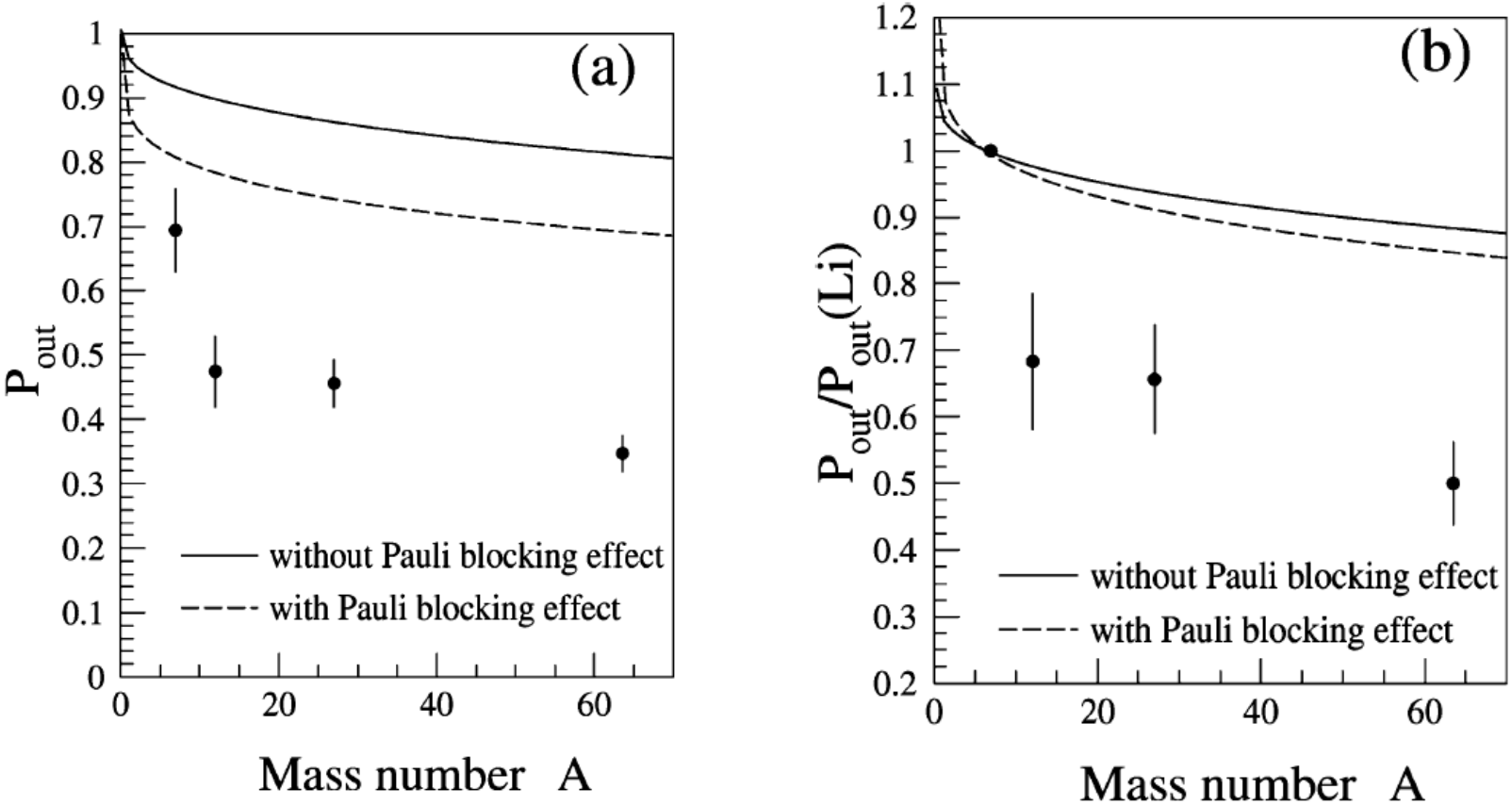
$$\sigma_A \propto A^{0.72 \pm 0.07}$$

$$\sigma_{\phi N} \; 34^{+17}_{-11} \text{ mb}$$

LEPS: $\gamma A \rightarrow \phi X$

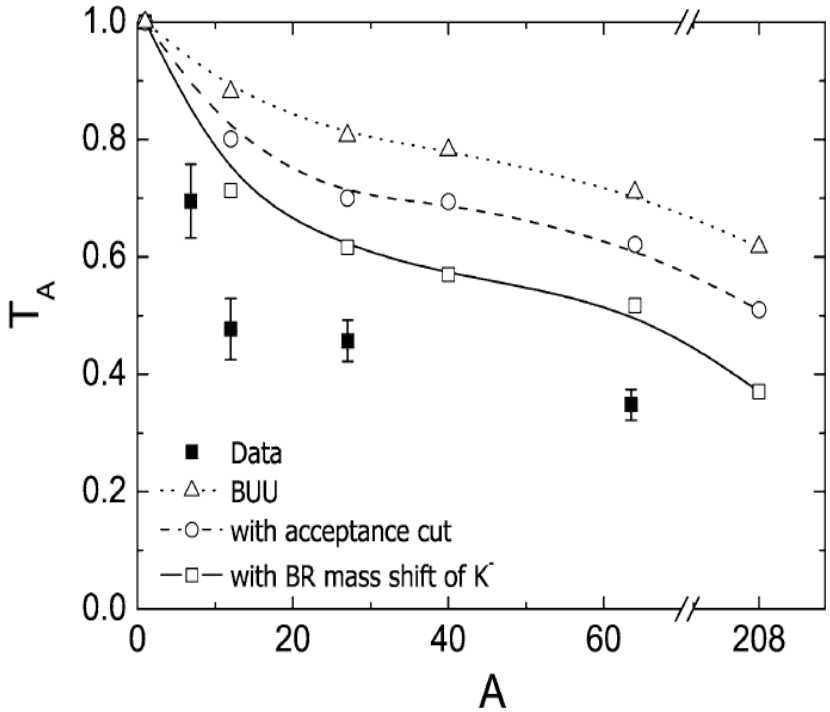
T. Ishikawa et al. (LEPS Collaboration) , Phys. Lett. B 608 (2005) 215–222

$$P_{\text{out}} = \sigma_A / (A\sigma_N)$$

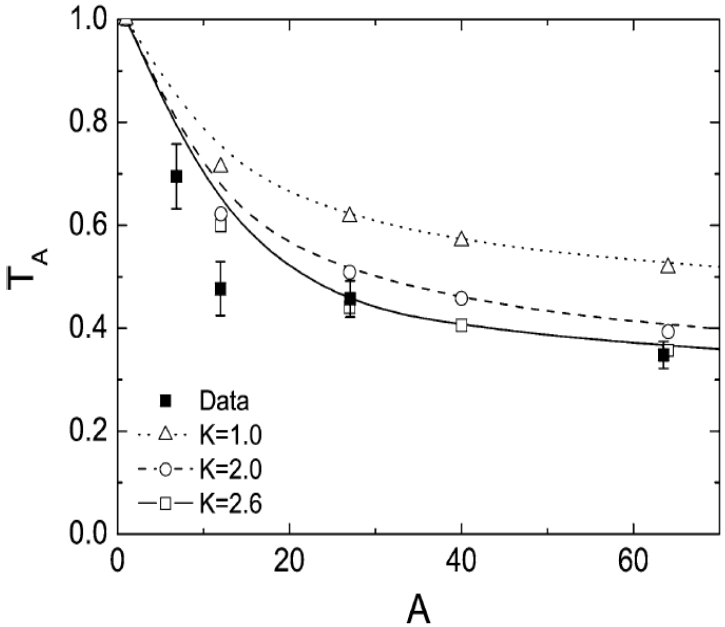


A suppression much stronger than theoretical calculations is observed.

P. Mühlich, U. Mosel / Nuclear Physics A 765 (2006) 188–196



$$\tilde{\sigma}_{\phi N} = K \cdot \sigma_{\phi N}. \quad \tilde{\sigma}_{\phi N} \simeq 27 \text{ mb}$$

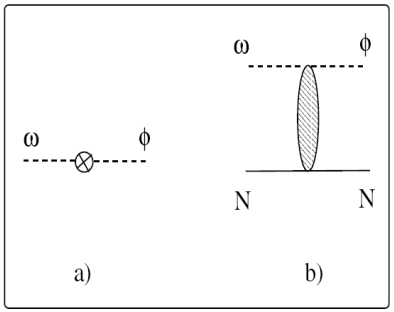


Model calculation includes:
- Fermi motion
- Pauli blocking
- Nuclear shadowing
- Quasi elastic scattering

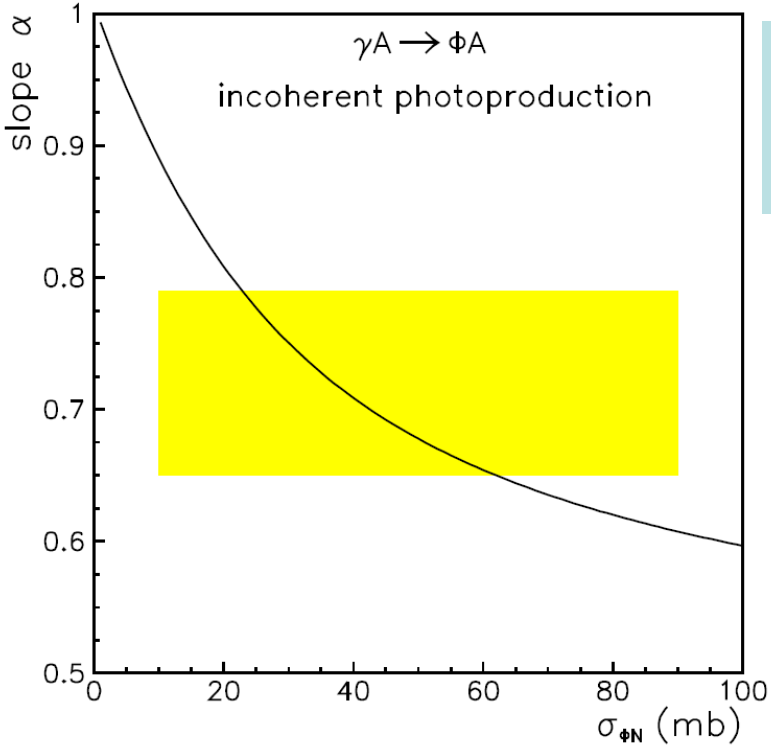
$$\phi N \to \phi N \qquad \phi N \to \pi N$$

the absorptive channel $\phi N \to 2\pi N$

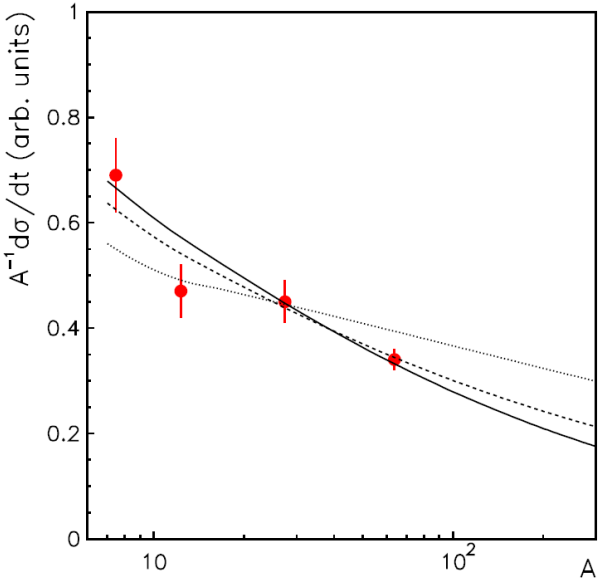
A. Sibirtsev, H.-W. Hammer, U.-G. Meiner, and A.W. Thomas,
Eur. Phys. J. A 29, 209-220 (2006)



$$23 \le \sigma_{\phi N} \le 63\,\mathrm{mb}$$



A-dependence of suppression can be reproduced with the inclusion of coupled-channel effects of $\omega N \to \phi N$ and $\pi N \to \phi N$.

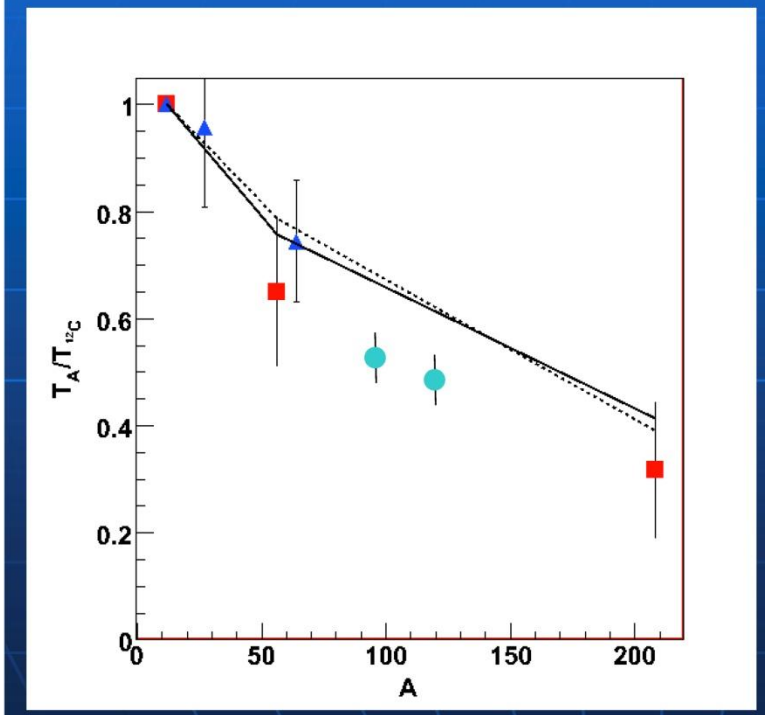


CLAS g7a: $\gamma A \rightarrow \phi X$

www.jlab.org/~mikewood/g7/g7a_job2007.ppt

Comparison to Expt. – ϕ Meson

Normalized to carbon data.



Giessen calculations

Giessen calculations w/ Spring8 absorption strengths

JLab (preliminary)

Spring8
T. Ishikawa et al. Phys. Lett. B 608, 215 (2005)

New JLab data

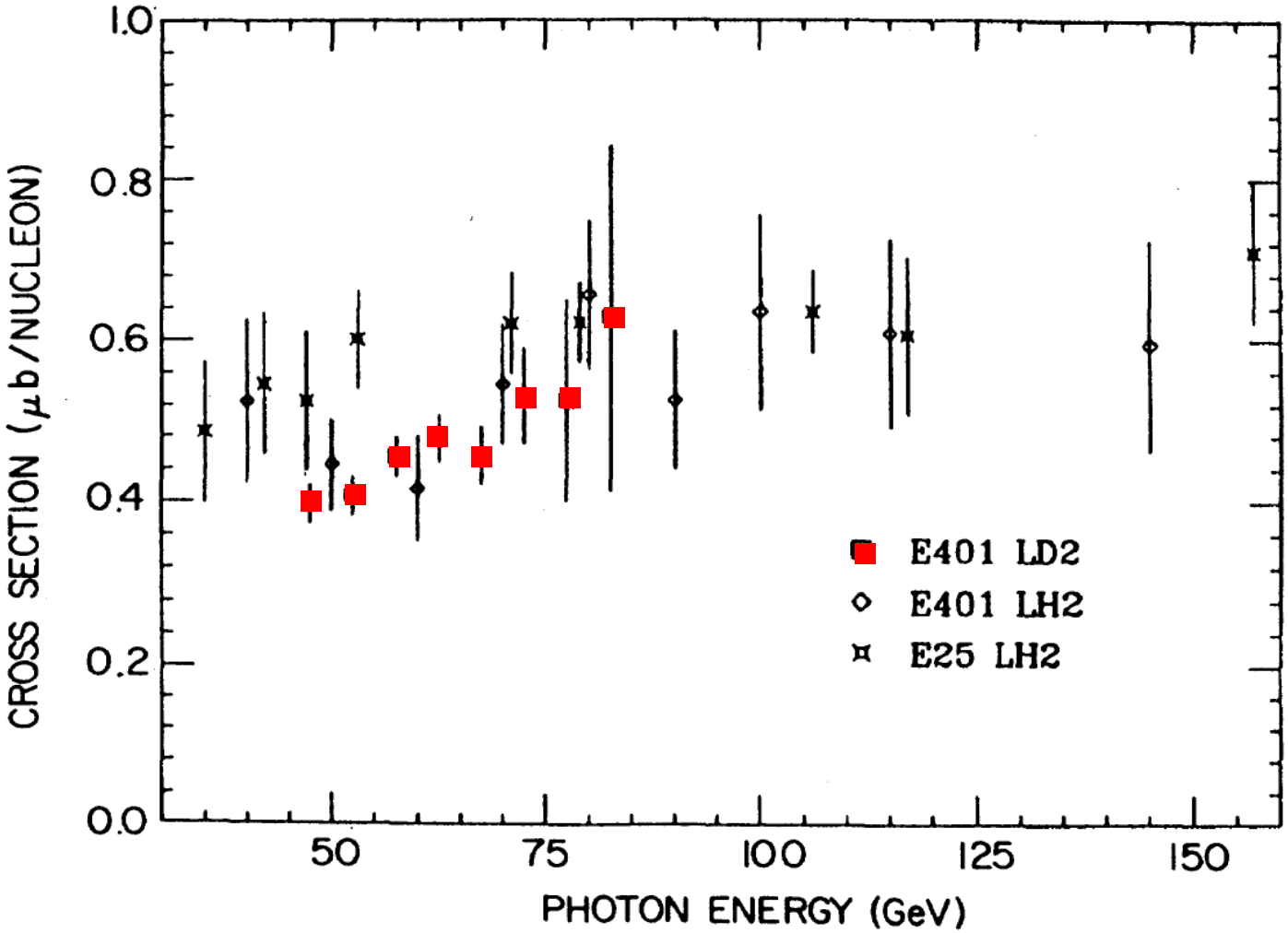
The Spring8 experiment was
$\gamma A \rightarrow \phi A' \rightarrow K^+K^- A'$
in the photon energy range of 1.5-2.4 GeV.

What Causes the Strong Attenuation of ϕ Yields in Nuclei?

- Theoretical speculations:
  - Absorption of ϕ after the interaction:
    - ***A large inelastic ϕN cross section*** *is required to explain the strong attenuation of ϕ flux from nuclei beyond standard scenario.*
    - The modification of self energy of ϕ in finite nuclear density region is speculated to be the main cause.
  - Loss of ϕ-flux before the interaction:
    - Two-step model with $\omega \leftrightarrow \phi$ mixing and coupling to π.
- Measurement of ϕ flux from the simplest nucleus, **deuterium**, where the nuclear density effect is minimal, shall be an important baseline to establish.

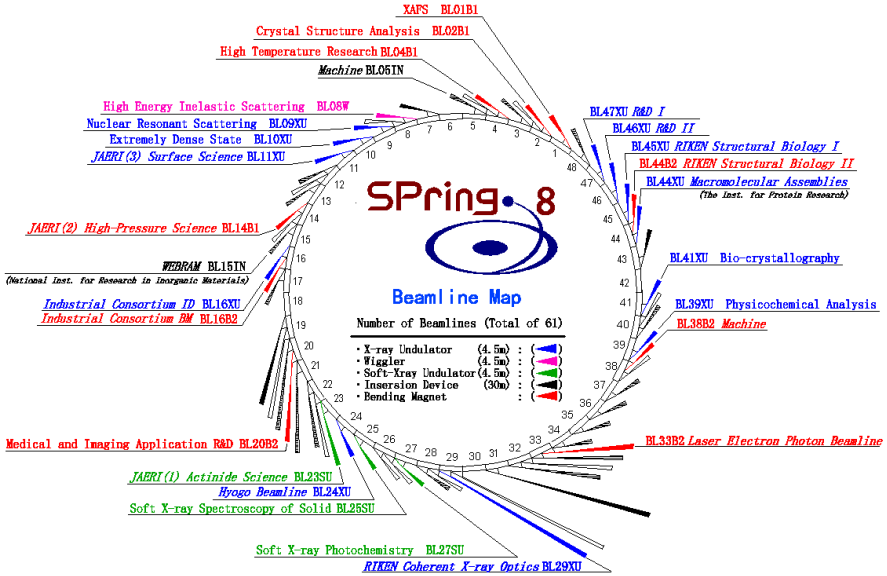
Cross Section of $\gamma p \rightarrow \phi p$ and $\gamma d \rightarrow \phi pn$ at E_γ=45-85 GeV

J. Busenitz et al., Phys. Rev. D 40, 1 (1989)

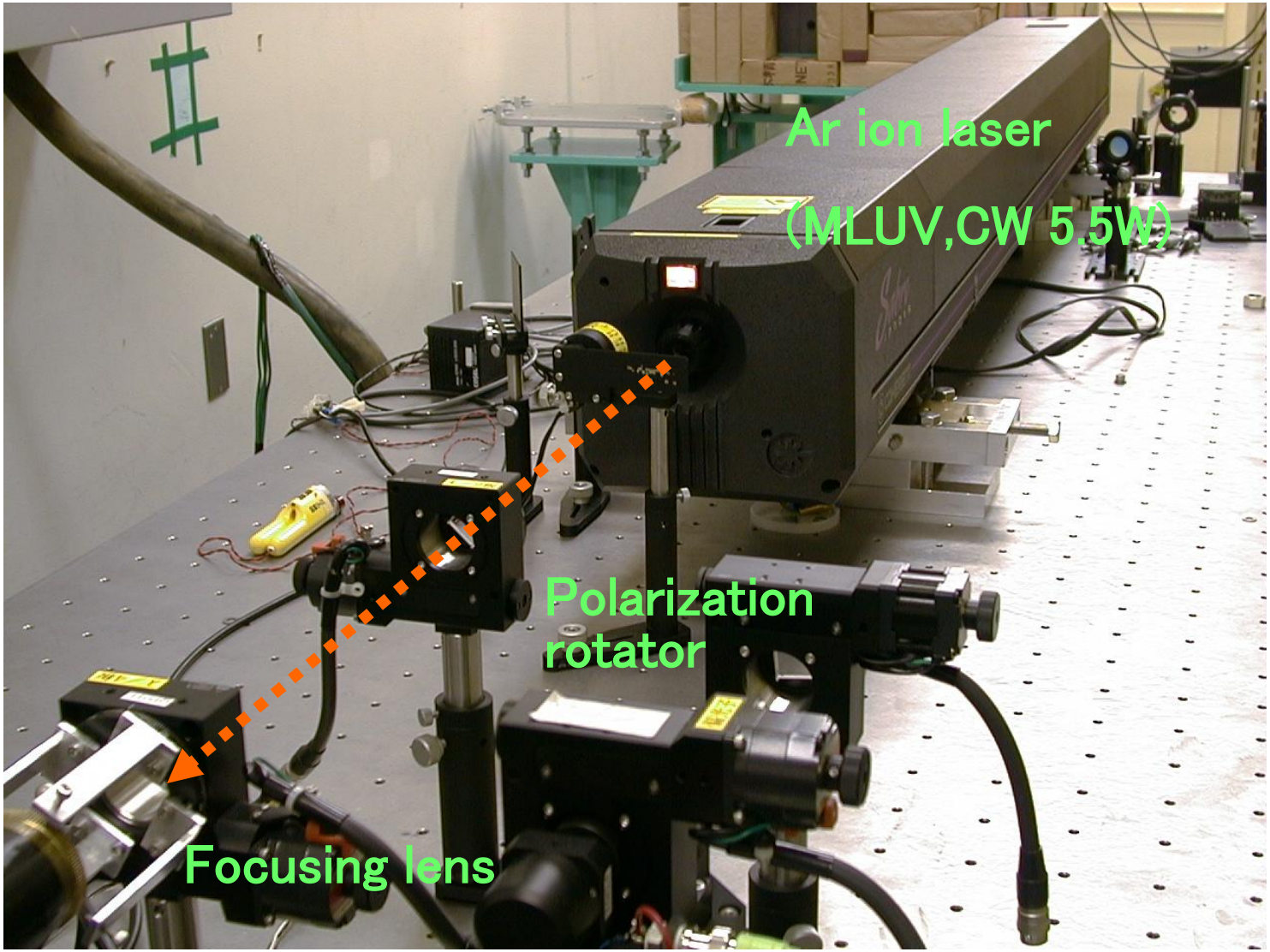


The yield per nucleon was same with hydrogen and deuterium target at high energies.

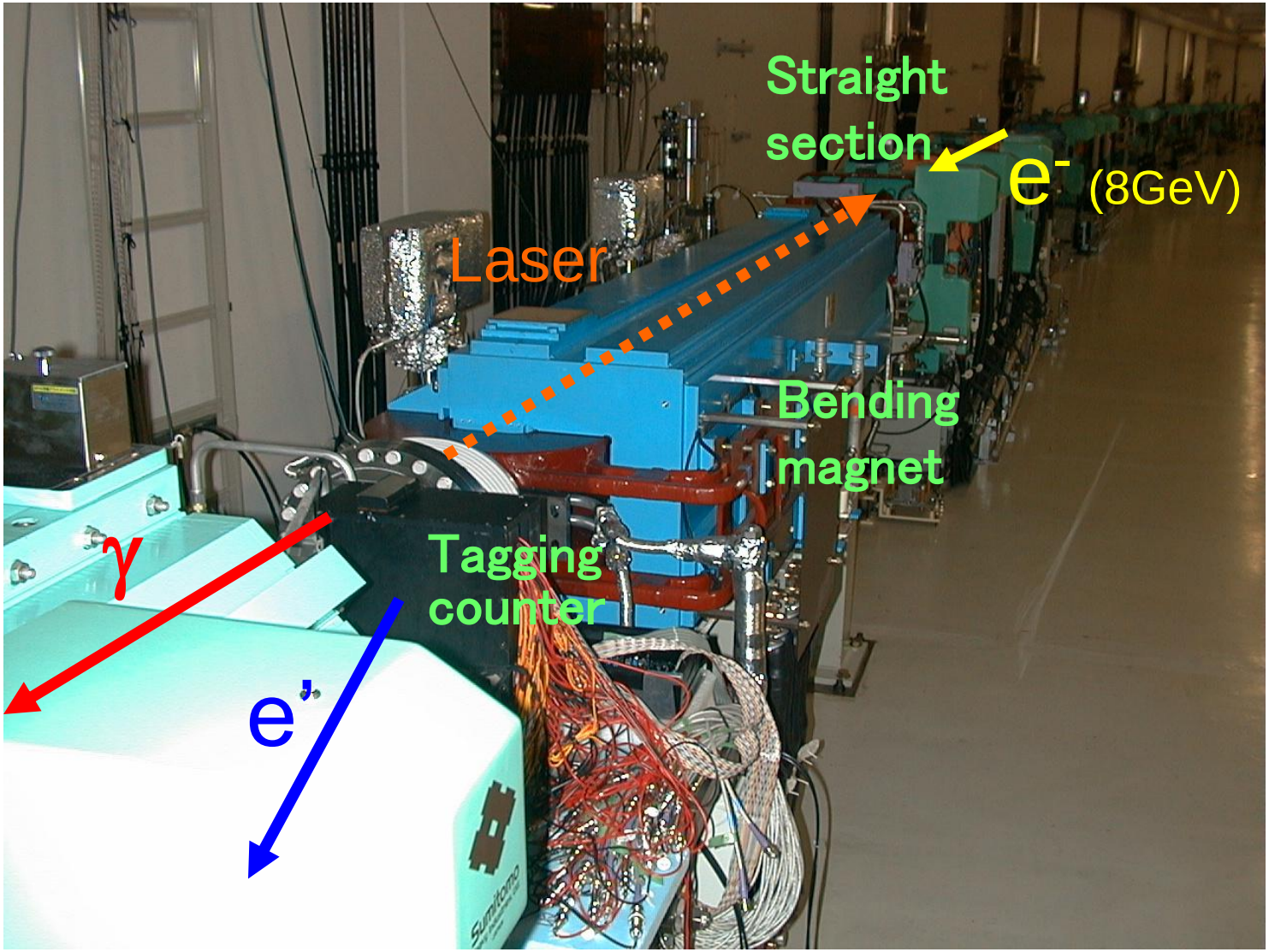
Super Photon Ring 8 GeV (SPring-8)



Laser System

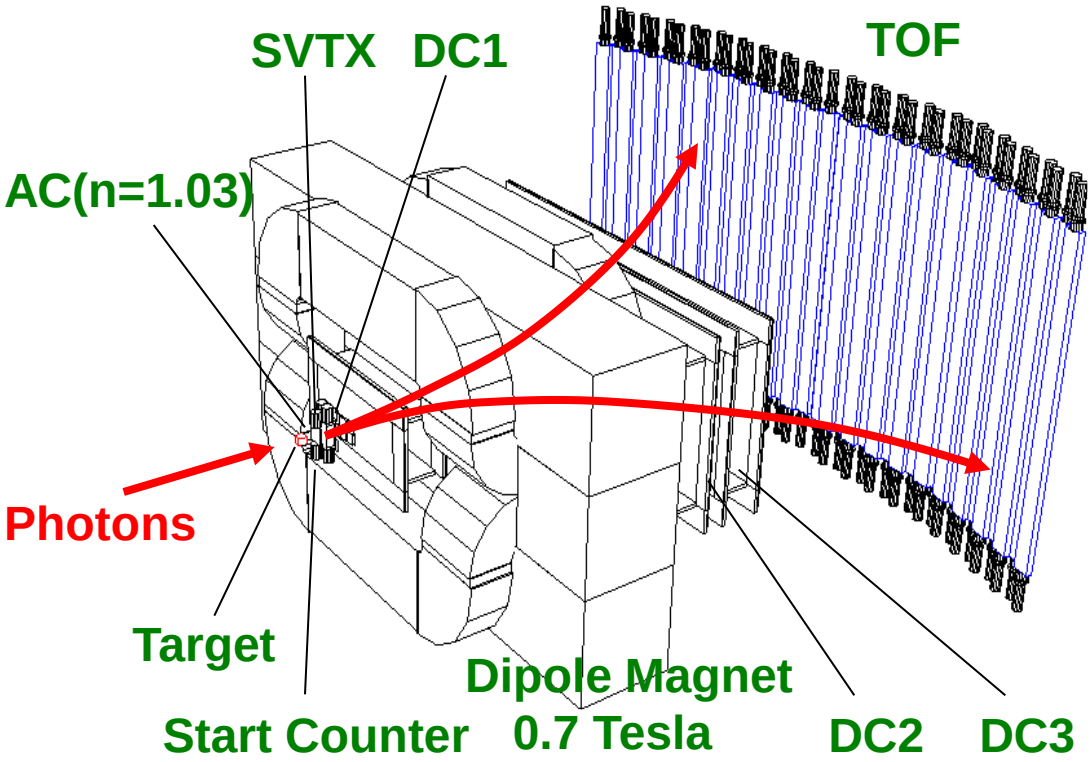


eγ Collision in Storage Ring

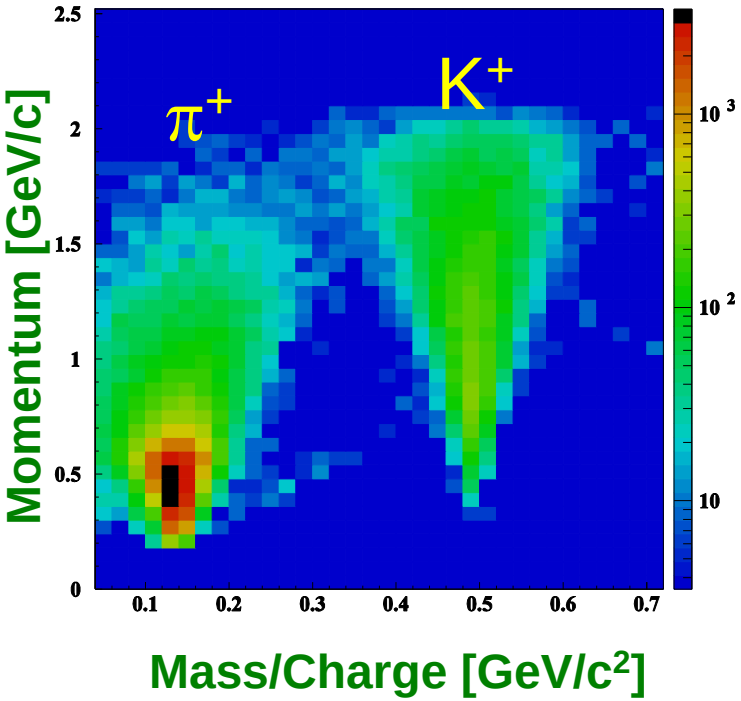


LEPS Spectrometer

Charged particle spectrometer with forward acceptance
PID from momentum and time-of-flight measurements

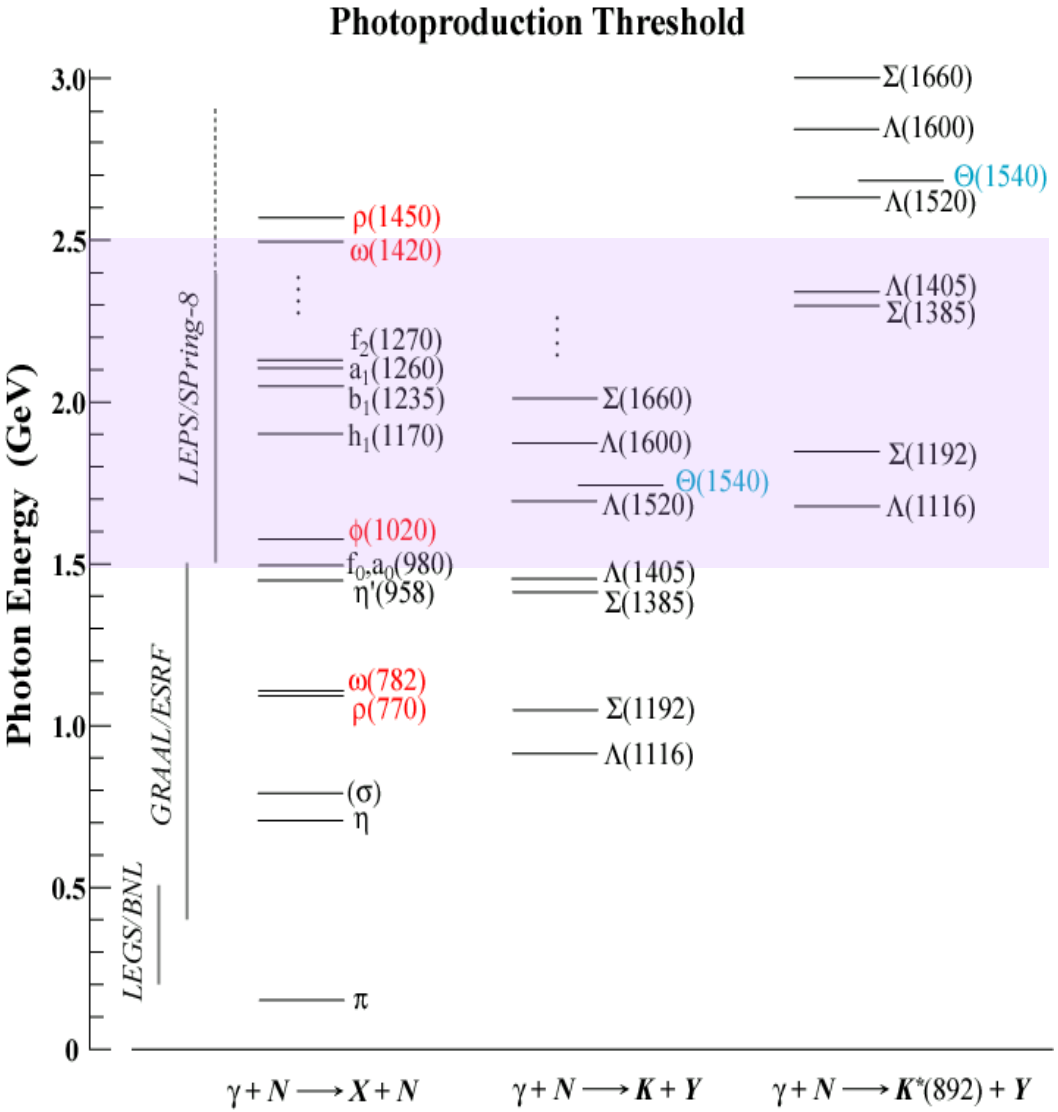


K/π separation



σ_P ~6 MeV/c for 1 GeV/c, σ_{TOF} ~150 ps,
σ_{MASS} ~30 MeV/c^2 for 1 GeV/c Kaon

Strangeness Production



Targets of study:

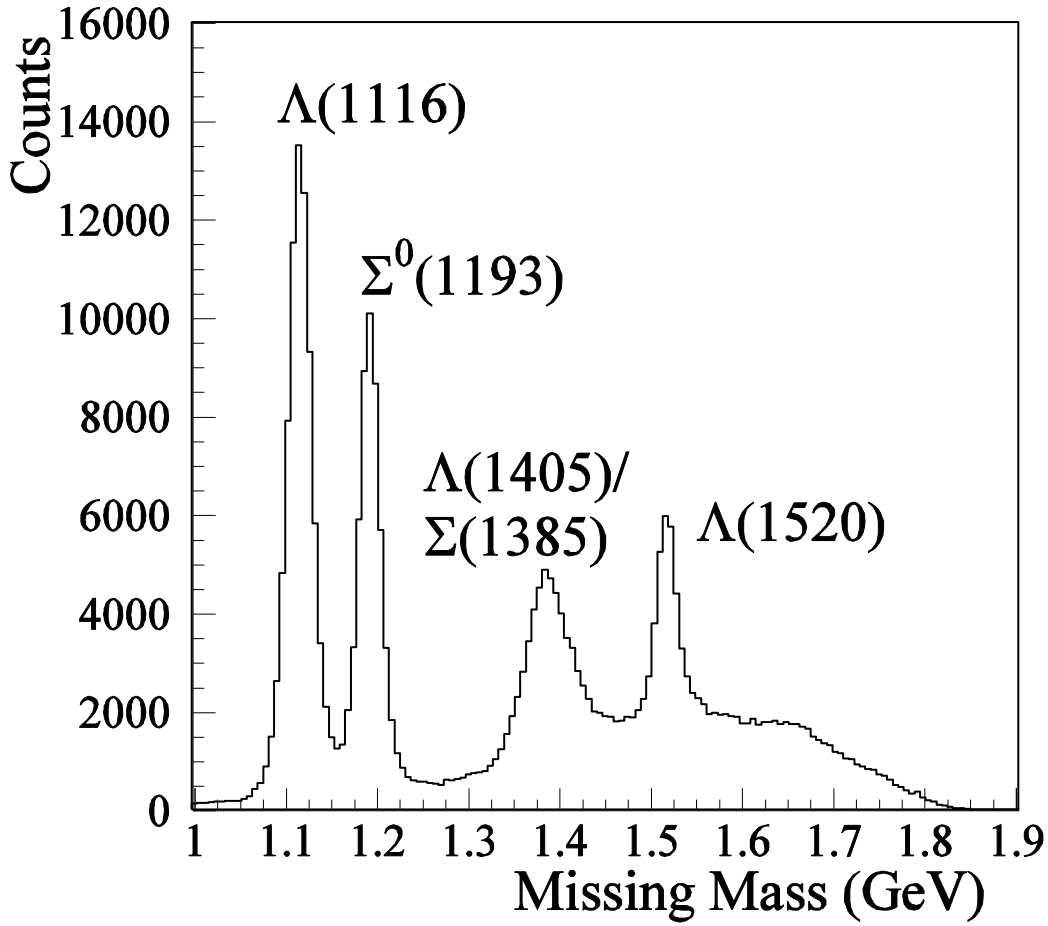
- **φ(1020)**
- **Λ, Σ hyperons**

Features:

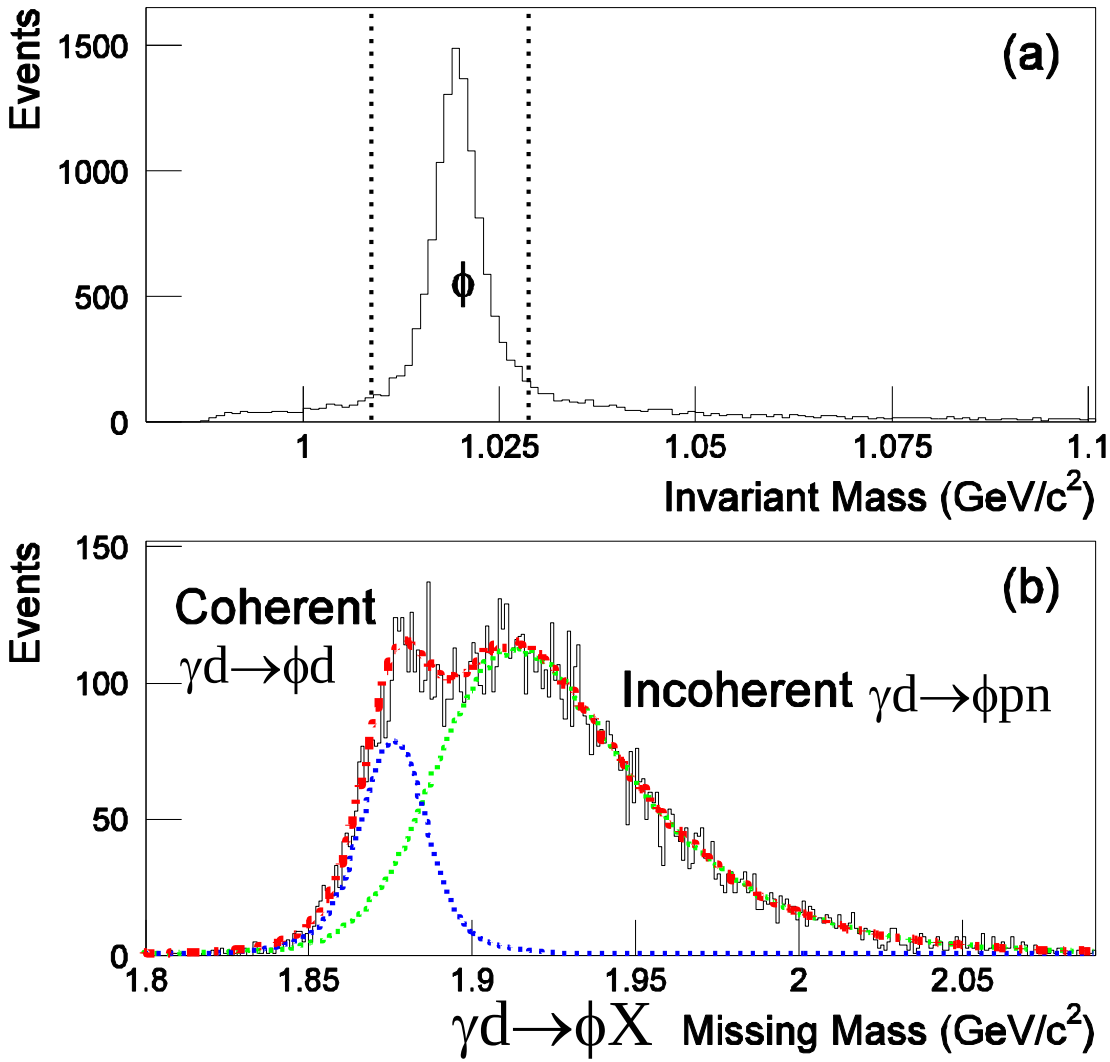
- **Forward angle measurement, including zero deg.**
- **Polarization observables.**
- **Strangeness production**

Session 3B: T. Nakano
"Recent results from LEPS"

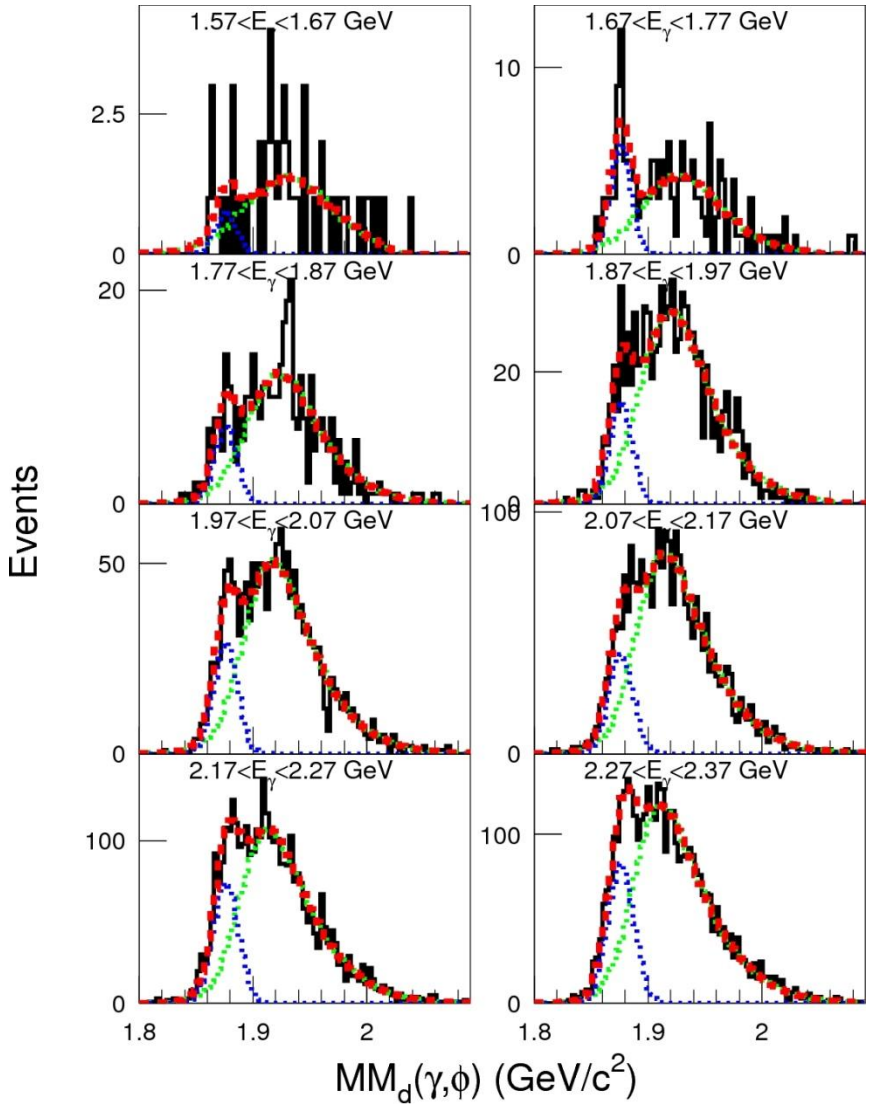
LEPS $\gamma p \rightarrow K^+X$

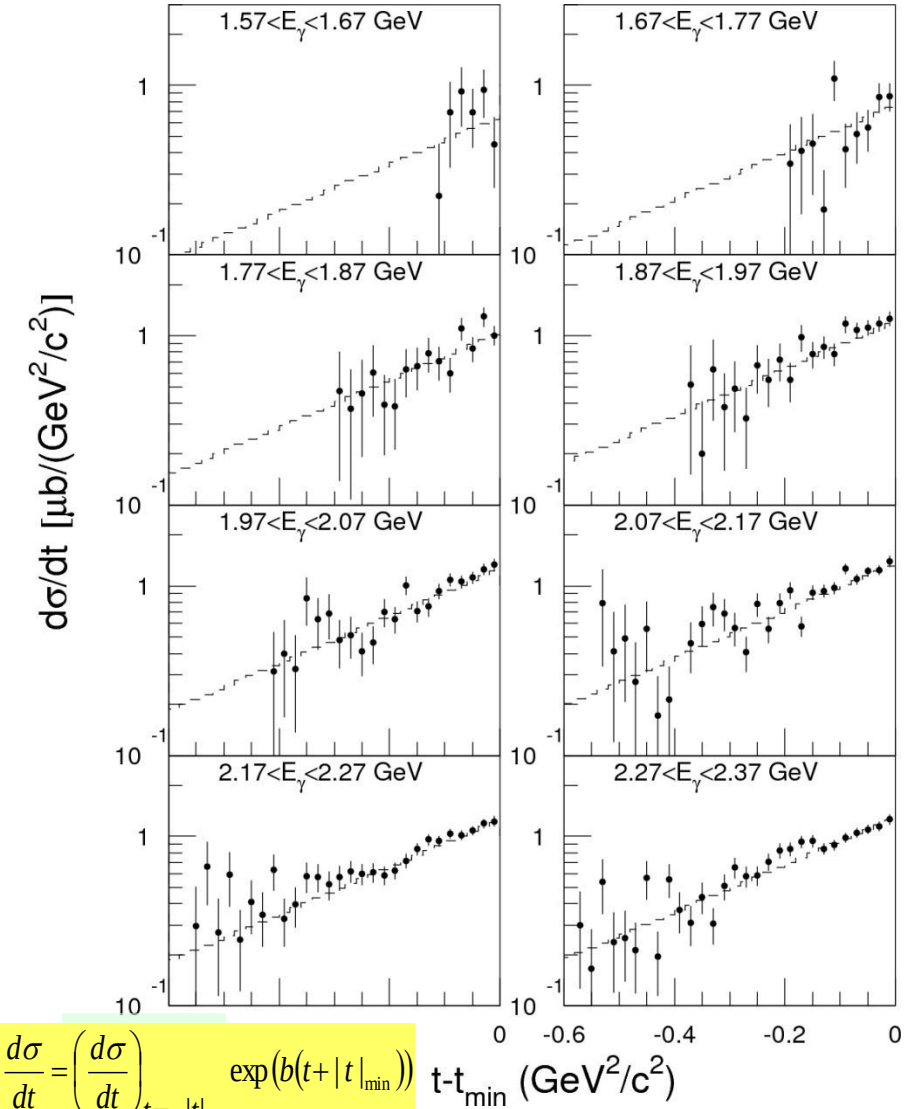


LEPS $\gamma d \rightarrow K^+K^-$ X



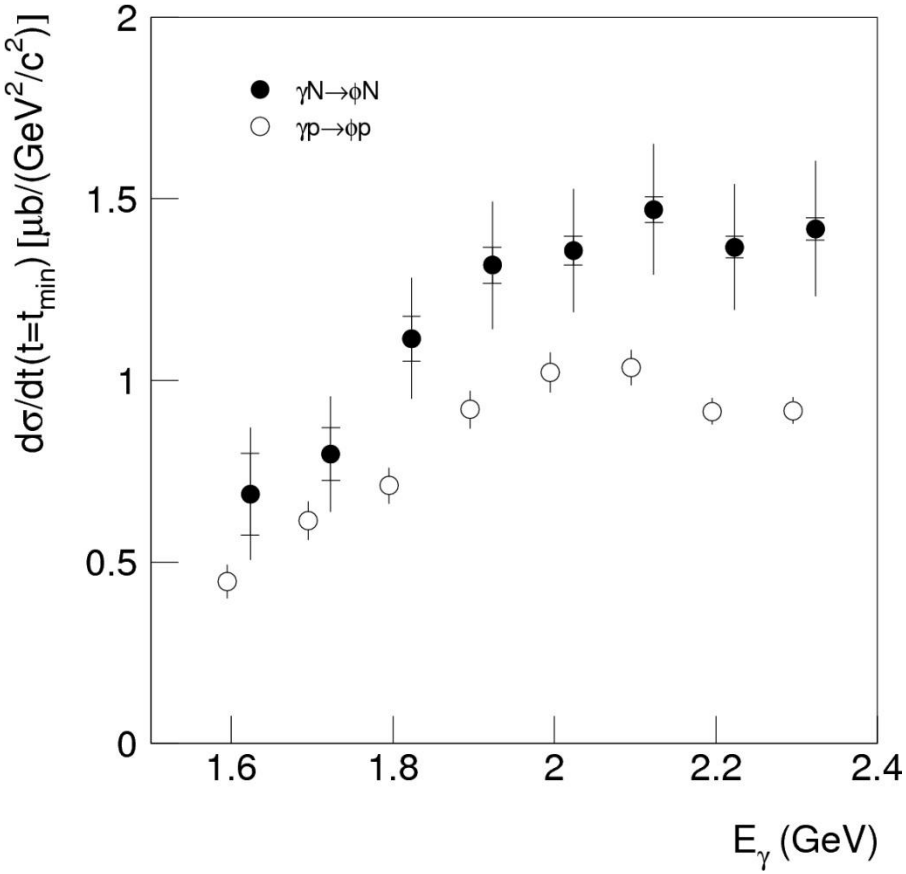
Differential Cross Sections of $\gamma d \rightarrow \phi pn$

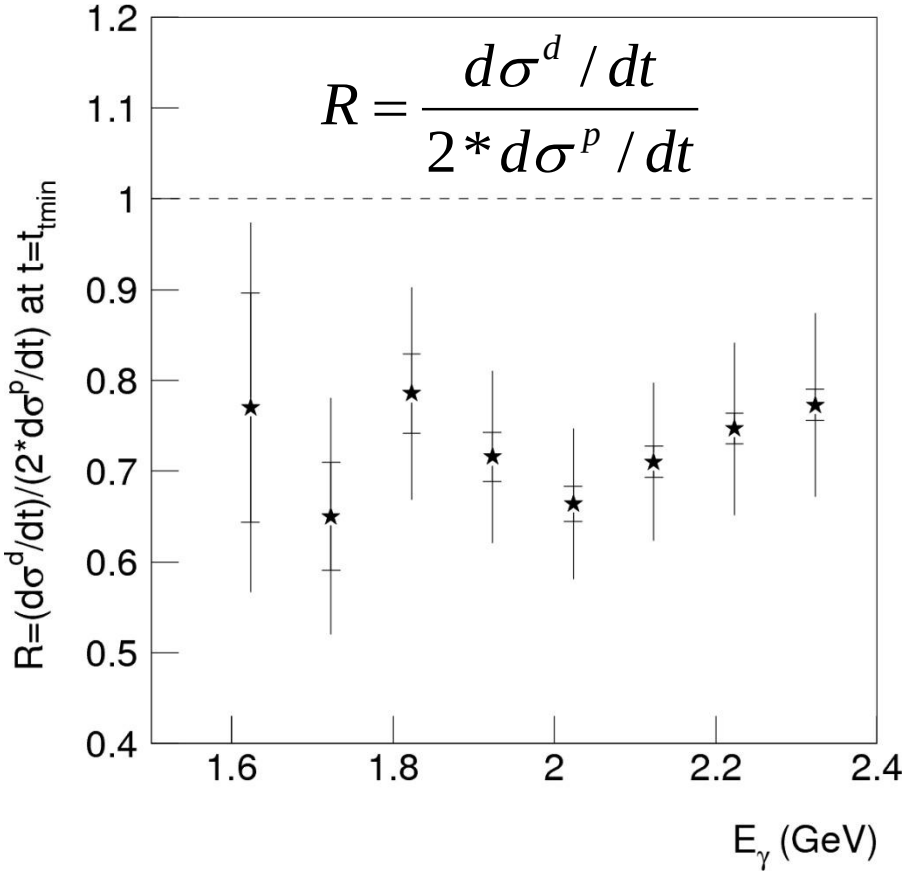




$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=-|t|_{min}} \exp\left(b\left(t+|t|_{min}\right)\right)$$

Differential Cross Sections and Nuclear Transparency Ratio of $\gamma d \rightarrow \phi pn$

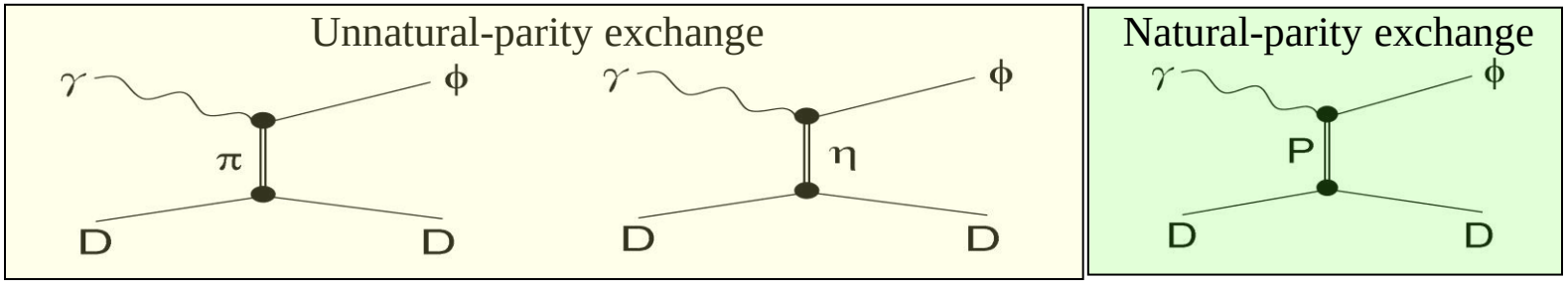




$$R = \frac{d\sigma^d / dt}{2 * d\sigma^p / dt}$$

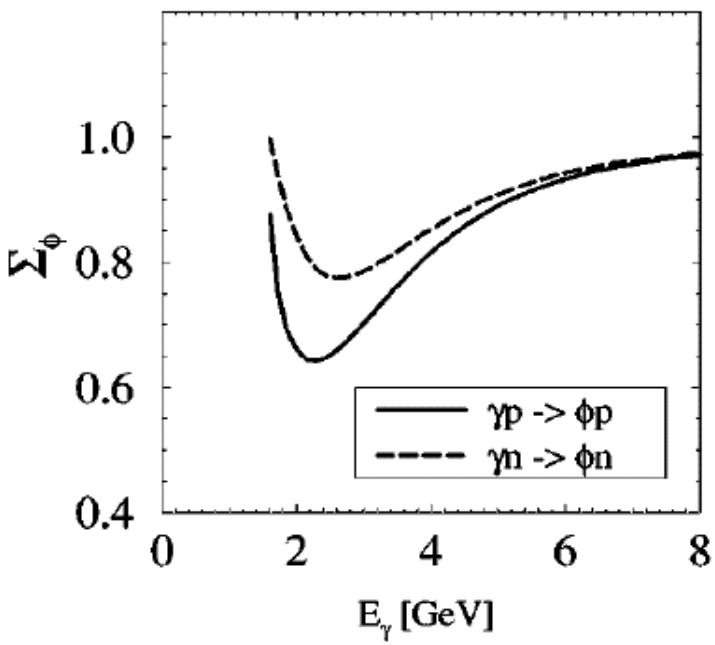
Strong suppression is seen with deuterium.

Isospin Effect



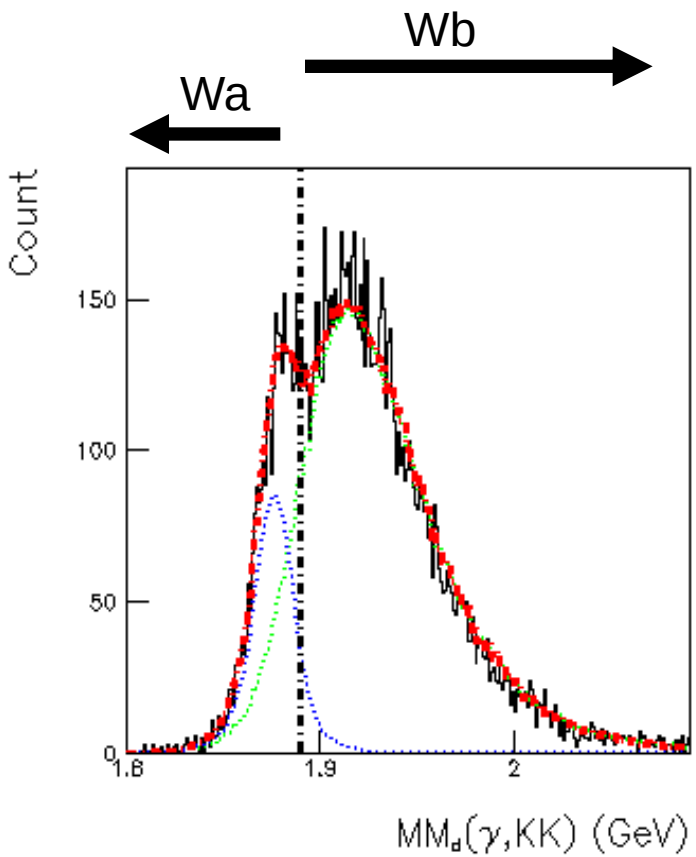
Due to isospin factor τ_3:

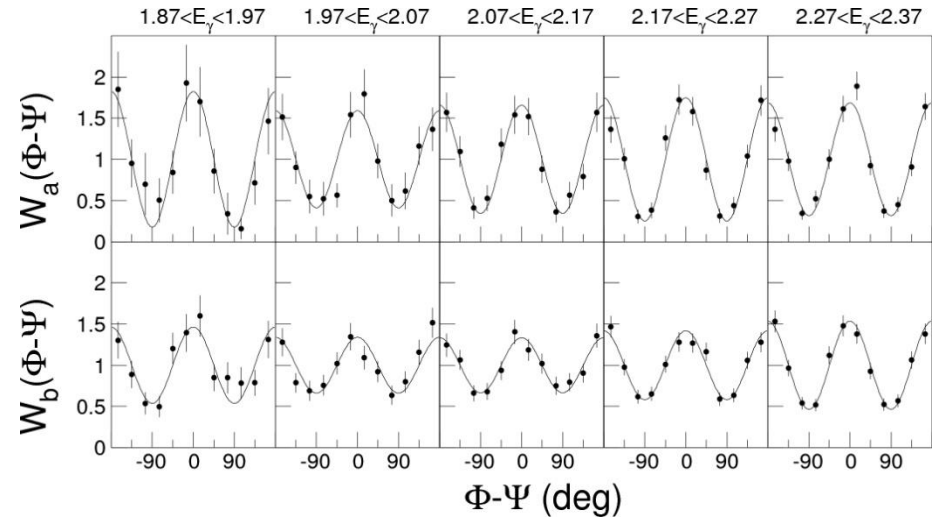
- $g_{\eta pp}$ and $g_{\pi pp}$ are of the same sign: *constructive* interference between η-exchange and π-exchange.
- $g_{\eta nn}$ (= $g_{\eta pp}$)and $g_{\pi nn}$ (=$-g_{\pi pp}$) are of opposite sign: *destructive* interference between η-exchange and π-exchange.
- Value of decay symmetry Σ gets closer to +1 in $\gamma n \rightarrow \phi n$, compared with $\gamma p \rightarrow \phi p$.



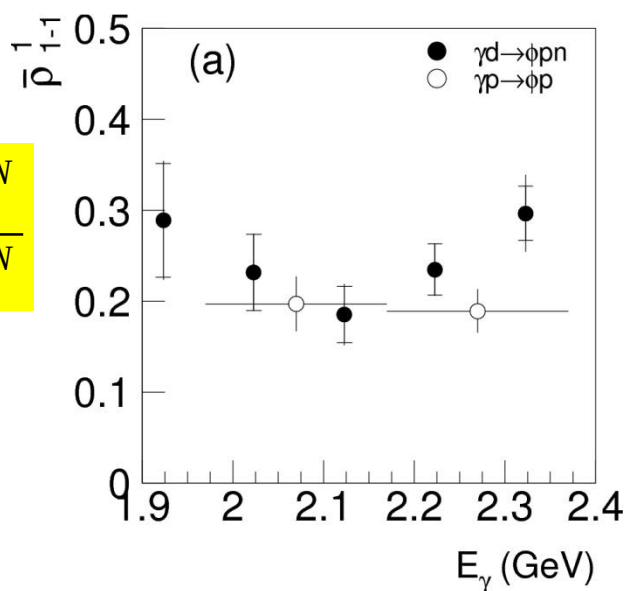
A. I. Titov, T.-S. H. Lee, and H. Toki, PRC 59, R2993 (1999)

Decay Angular Distributions at $|t-t_{min}^{d}|<0.1$ GeV^2

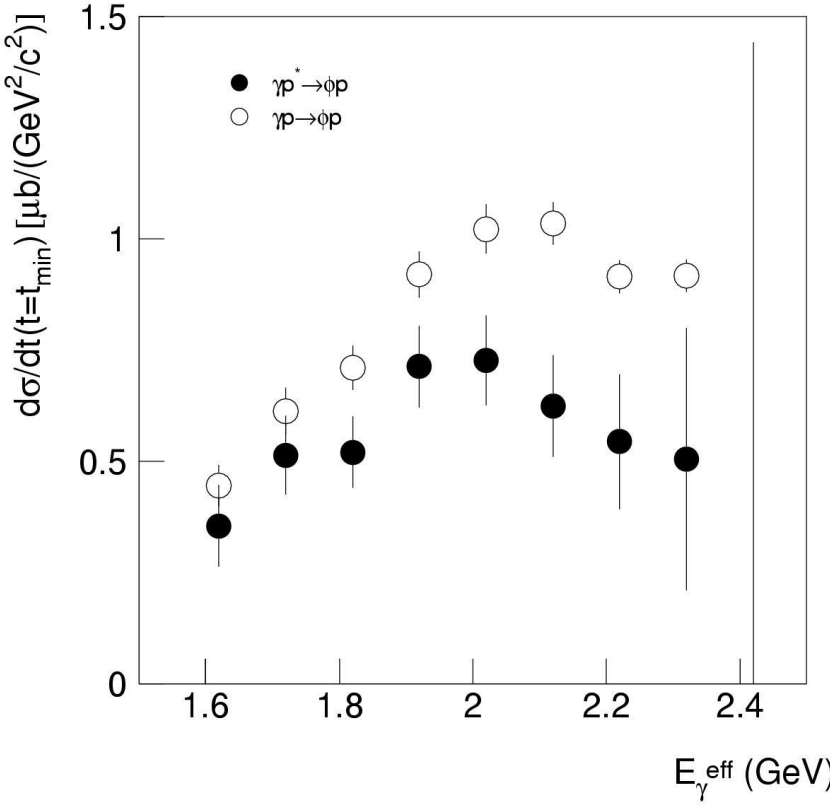


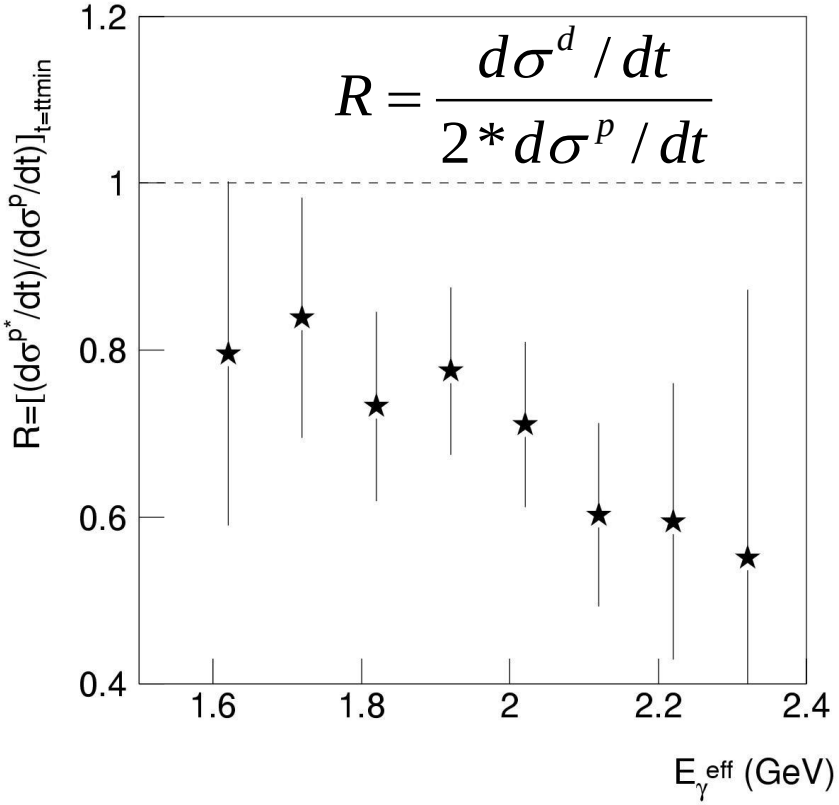


$$\bar{\rho}^{1}_{1-1} \approx 0.5 * \frac{\sigma^{N} - \sigma^{UN}}{\sigma^{N} + \sigma^{UN}}$$



Differential Cross Sections of Incoherent Production $\gamma p^* \rightarrow \phi p$

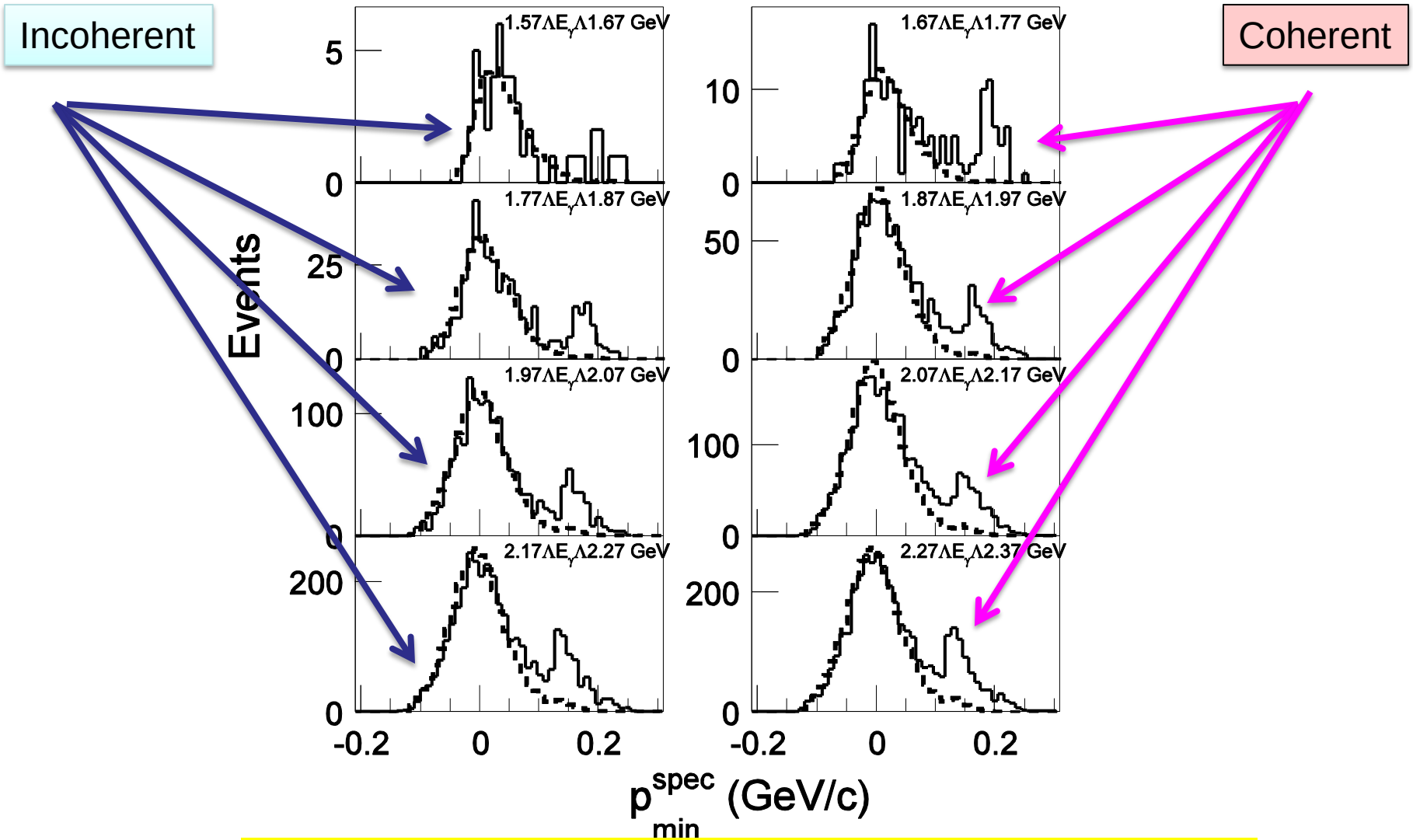




$$R = \frac{d\sigma^d / dt}{2 * d\sigma^p / dt}$$

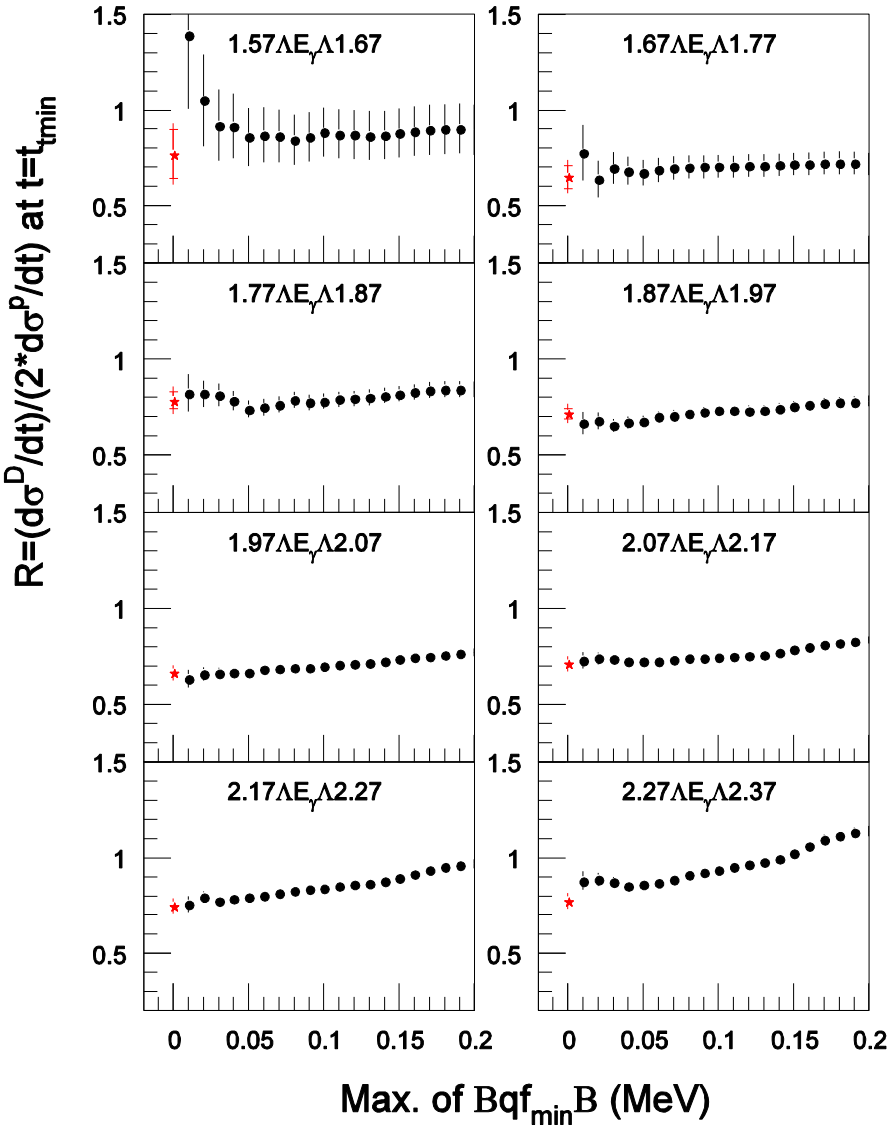
Suppression is common for production from either proton or neutron.

Distributions of Estimated Fermi Momentum



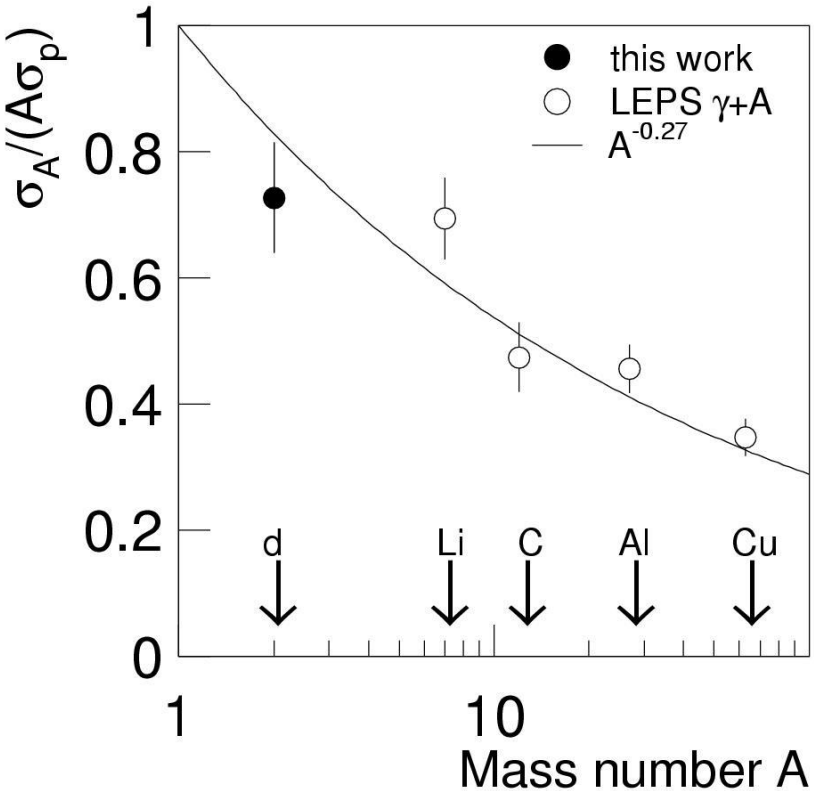
Rescattering loss due to final-state N-N interaction is small.

Nuclear Transparency Ratio of $\gamma d \rightarrow \phi pn$ as a function of Fermi-momentum cut



*: ratios obtained by the disentanglement method

Mass Number Dependence of Nuclear Transparency ratio



- Strong suppression is already present in the production with deuterium.
- Non-negligible nuclear structure effect contributes to the suppression.

Summary

- A strong suppression of ϕ photoproduction is observed in the nuclear transparency ratio of deuterium target.
- Effect of isospin asymmetry in the production is small.
- Suppression is common for production from either proton or neutron.
- **The nuclear structure effect should be taken into account in the observed suppression with nuclei targets before ensuring the nuclear density effect.**
- Long-range interactions other than standard Pomeron exchange is needed to explain the reduction, e.g. $\omega \leftrightarrow \phi$ mixing, $\phi \leftrightarrow KK$, at low energies.

The LEPS Collaboration

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