ϕ and ω mesons in a nuclear medium and the nuclear photoproduction reaction

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Introduction

- The study of vector meson properties could be useful to find evidence of a possible partial restoration of chiral symmetry at finite ρ , T
- Particularly suited probes: electromagnetic decays (dileptons)

ρ meson has been extensively studied, dilepton spectrum from HIC's may indicate a lowering of M_ρ or large increase of Γ_ρ

R. Rapp, J. Wambach, Adv. Nucl Phys. 25 (2000) 1

- Narrow vector mesons (ω, ϕ) have received comparatively less attention

Interesting theoretical problems associated!

Introduction

- The ϕ meson is an appropriate probe for *dynamics of vector mesons in nuclear matter*
  - *Isolated* in the mass spectrum
  - Changes of properties comparatively *larger* than other mesons

Experimental observation in principle easier

- ϕ properties in nuclear medium strongly related to the renormalization of kaon properties
  - *Kaon selfenergy*
    - Variety of models, predict different kaon potentials
    - Good reproduction of data (*K-atoms, HIC*)
  - *Kaon condensation* → astrophysical implications

Experimental information from ϕ decay
→ *valuable info on kaon selfenergy*

Introduction

Proposed reactions to test ϕ, ω properties in nuclear medium

AA, pA collisions

$\pi^- p \to \phi n$ in nuclei

$\gamma N \to \phi N, \omega N$ in nuclei

Experiments

KEK-PS ☺

Very recent analysis from p-A reaction, presented in Chiral'05 and Quark Matter '05

LEPS ☺

Recent experimental data from nuclear inclusive ϕ photoproduction reaction

CB-TAPS@ELSA ☺

Very recent experimental data from nuclear ω photoproduction reaction

Near future...

HADES, CLAS (preliminary)

ϕ meson: Outline

ϕ meson mass and decay width in the nuclear medium – a selfenergy approach.

Experimental information: study of inclusive nuclear ϕ photoproduction.

D. Cabrera and M.J. Vicente Vacas, Phys. Rev C 67, 045203 (2003)

D. Cabrera, L. Roca, E. Oset, H. Toki and M.J. Vicente Vacas, Nucl. Phys. A 733 (2004) 130

Theoretical approaches to ϕ meson properties

ϕ mass

Effective Lagrangian approach

Weise et al.; Kuwabara and Hatsuda; Song; Bhatttachayya et al.

QCD sum rules

Asakawa and Ko; Kampfer et al.

ϕ decay width

Dropping of meson masses

Bhattacharyya et al.; Ko et al.; Shuryak et al.; Panda et al.

Collisional broadening by ϕ-baryon and ϕ-meson interactions

Smith and Haglin; Alzarez-Ruso and Koch

Modification of ϕ decay channels (ϕ selfenergy approach, kaon selfenergies)

Weise et al.; Ramos et al.

→ Sizable renormalization of ϕ width

and small mass shift in nuclear medium

ϕ meson selfenergy in vacuum

- Interested in the ϕ to $\bar{K}K$ coupling ⟶ main ϕ decay channel in vacuum, BR 85% (ignore other contributions).

$\phi \bar{K}K$ Lagrangian in a gauge vector representation

J. Schechter et al. 1988

W. Weise et al. 1998

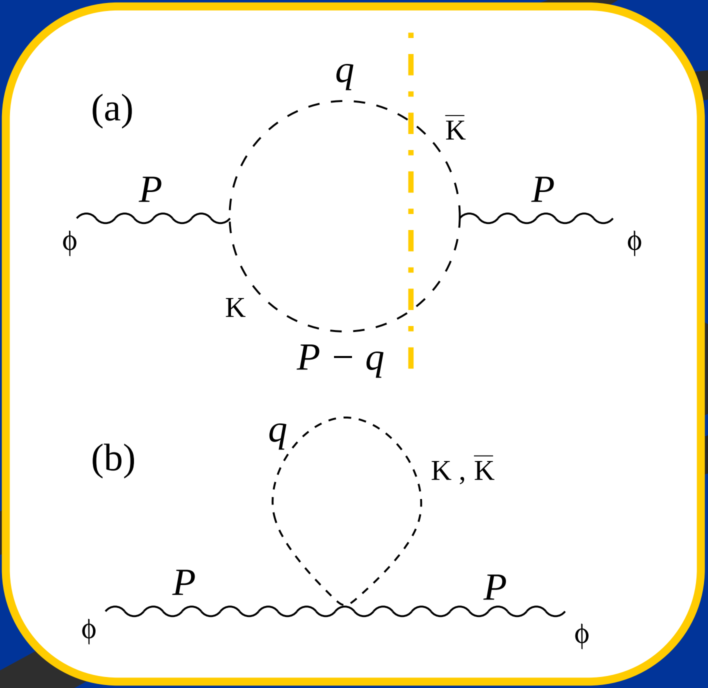
$$\mathcal{L}_{\phi,kaons} = -ig_\phi \phi_\mu (K^-\partial^\mu K^+ - K^+\partial^\mu K^- + \bar{K}^0\partial^\mu K^0 - K^0\partial^\mu \bar{K}^0) + g_\phi^2 \phi_\mu \phi^\mu (K^-K^+ + \bar{K}^0 K^0) \, ,$$

Gives rise to a ϕ selfenergy built from:

- *$\bar{K}K$ loop diagram*
- *Kaon tadpole diagram*

$$\mathrm{Im}\,\Pi_\phi \rightarrow \Gamma_\phi = f(g_\phi)$$

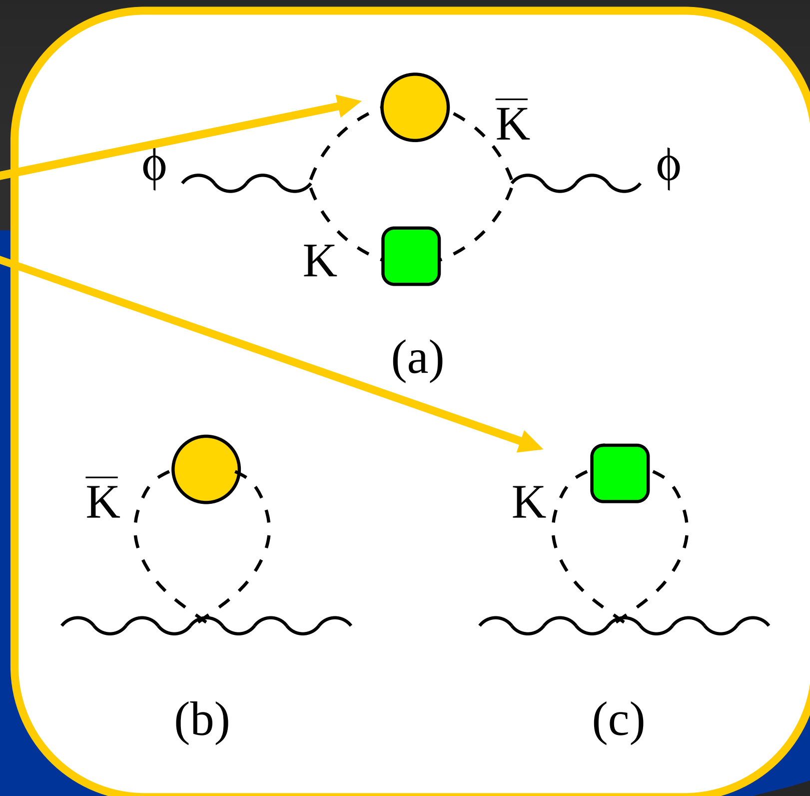
$$\Gamma^{\exp}_{\phi \rightarrow K^+K^-} \rightarrow g_\phi = 4.57$$



Nuclear medium effects

We modify the kaon propagators with selfenergy accounting for interactions with the nuclear medium

$$\Pi_{\bar{K}(K)}(q^0,\vec{q};\rho)$$



$$\Pi^{ij}_{\phi}(P^0;\rho) = \delta^{ij} i2g_{\phi}^2\frac{4}{3}\int \frac{d^4q}{(2\pi)^4}\vec{q}^{\,2} D_K(P-q;\rho)D_{\bar{K}}(q;\rho)$$
$$+\delta^{ij} i2g_{\phi}^2\left\{\int \frac{d^4q}{(2\pi)^4} D_{\bar{K}}(q;\rho) + \int \frac{d^4q}{(2\pi)^4} D_K(q;\rho)\right\}$$

$$D_{\bar{K}(K)}(q) \Rightarrow D_{\bar{K}(K)}(q^0,\vec{q};\rho)$$

Kaon selfenergy: S-wave

Kaon and anti-kaon interactions with nucleons are rather different
→ we treat them separately

- *KN:* smooth at low energies, since there are not *S*=1 resonances (?)
  We use $t\rho$ aproximation

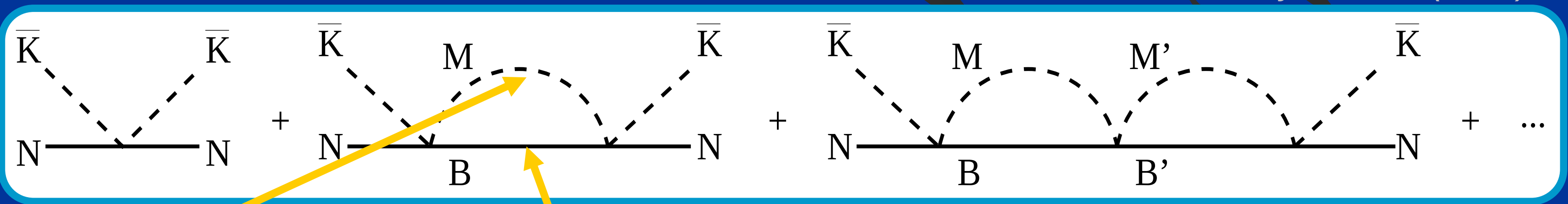
$$\Pi_{K^+} = \frac{1}{2}(t_{K^+p} + t_{K^+n})\rho = 0.13\, m_K^2 \frac{\rho}{\rho_0}$$

N. Kaiser, P.B. Siegel and W. Weise, Nucl. Phys. A 594 (1995) 325

- *$\bar{K}N$:* strongly dominated by the excitation of *sub-threshold* Λ(1405).

Chiral unitary model in coupled channels for *S-wave $\bar{K}N$* scattering

E. Oset and A. Ramos, Nucl. Phys. A 635 (1998) 99



π and *K* selfenergies

Pauli blocking

Mean-field potentials

Selfconsistent calculation of the *S*-wave selfenergy

A. Ramos and E. Oset, Nucl.Phys. A 671 (2000) 481

Kaon selfenergy: P-wave

Σ^*=Σ^* (1385)

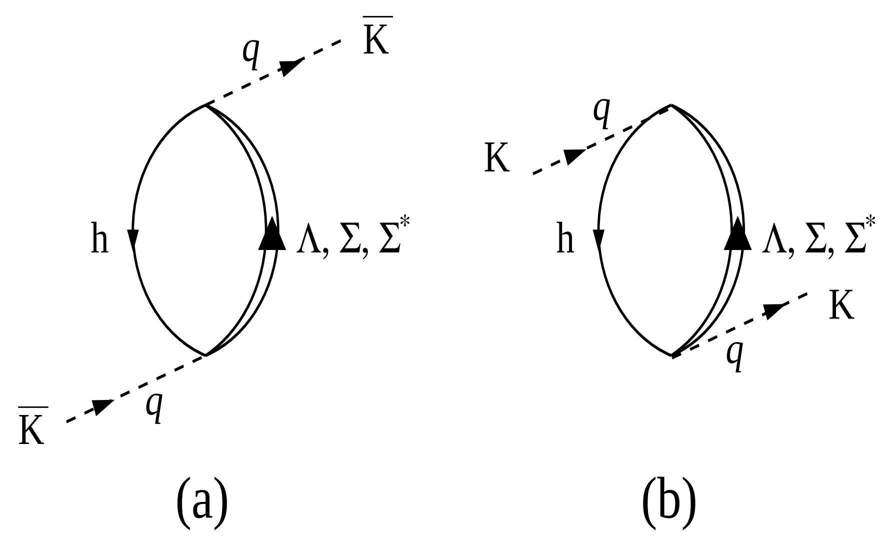
Built from Λh, Σh and $\Sigma^* h$ excitations, found to be an important source of ϕ renormalization in a nuclear medium.

Klingl, Waas and Weise 98; Oset and Ramos 01

KNY interaction from lowest order chiral Lagrangian coupling pseudoscalar meson and 1/2$^+$ baryon octets.

$$\Pi^P_{\bar{K}}(q,\rho) = \frac{1}{2}\tilde{V}^2_{K^- p\Lambda} f^2_\Lambda(q)\,\vec{q}^{\,2} U_\Lambda(q,\rho) + \frac{3}{2}\tilde{V}^2_{K^- p\Sigma^0} f^2_\Sigma(q)\,\vec{q}^{\,2} U_\Sigma(q,\rho) + \frac{1}{2}\tilde{V}^2_{K^- p\Sigma^{*0}} f^2_{\Sigma^*}(q)\,\vec{q}^{\,2} U_{\Sigma^*}(q,\rho)$$

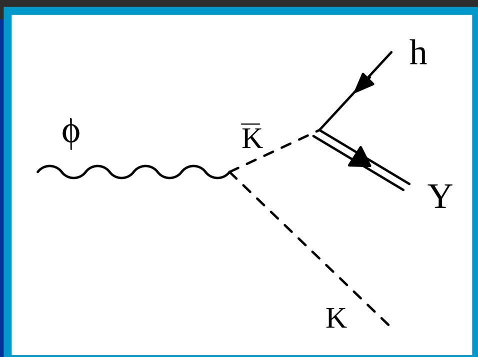
$$\Pi^P_K(q^0,\vec{q};\rho) = \Pi^P_{\bar{K}}(-q^0,\vec{q};\rho)$$

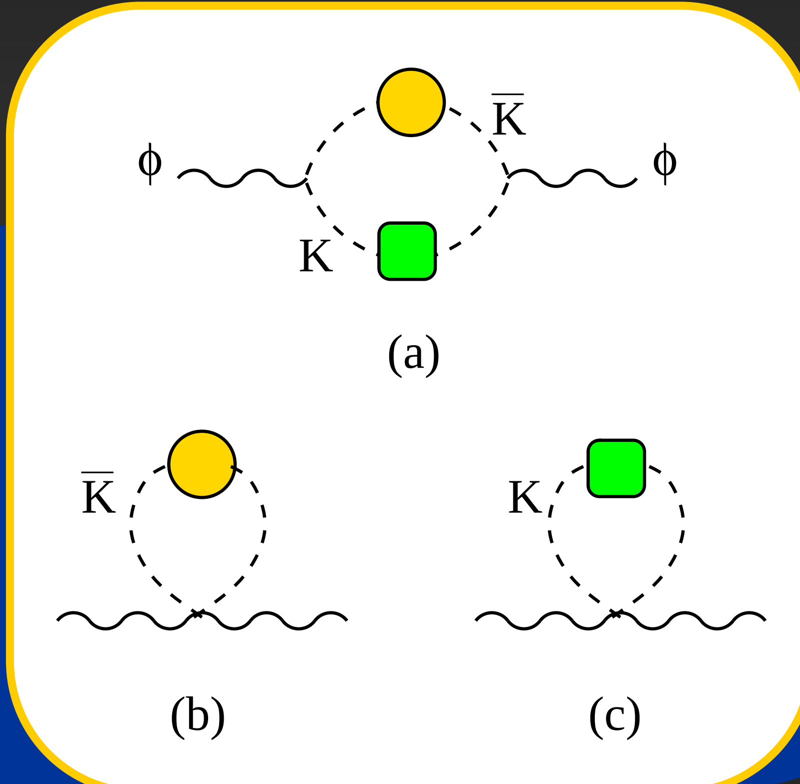


ϕ meson selfenergy in the medium

ϕ decay channels which open in the medium due to Π_K :

- *S*-wave: $\phi \to KM\ Yh \quad (\pi\Sigma, \pi\Lambda)$
- *P*-wave: $\phi \to K\ Yh$





Use of spectral (Lehmann) representation for kaon, anti-akon propagator, guarantees *crossing*

$$D_{\bar{K}(K)}(-q^0,\vec{q};\rho) = D_{K(\bar{K})}(q^0,\vec{q};\rho)$$

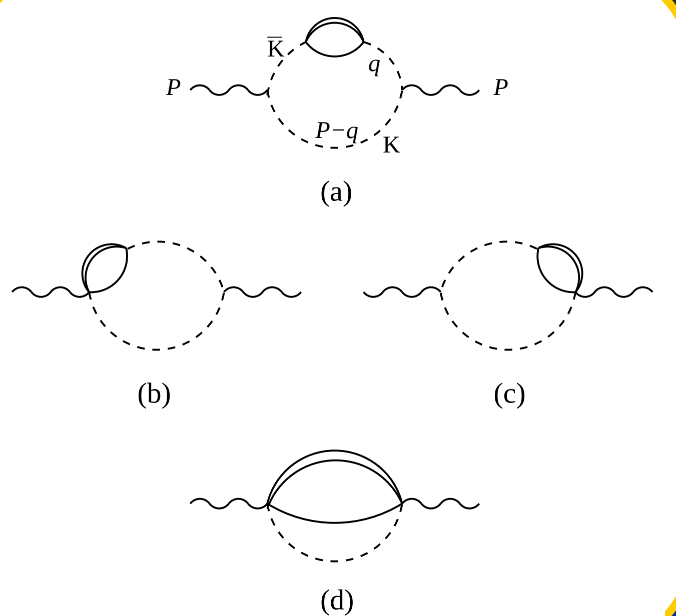
Kaon propagator:

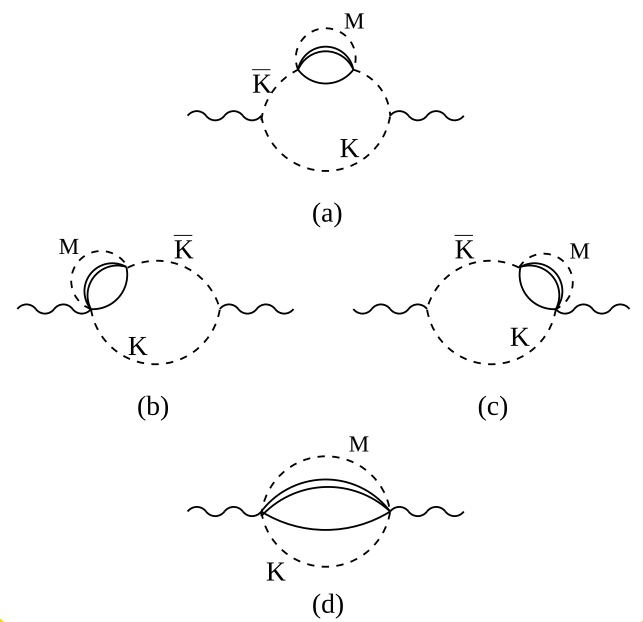
$$D_{\bar{K}(K)}(q^0,\vec{q};\rho) = \int_0^\infty d\omega \left\{ \frac{S_{\bar{K}(K)}(\omega,\vec{q};\rho)}{q^0-\omega+i\eta} - \frac{S_{K(\bar{K})}(\omega,\vec{q};\rho)}{q^0+\omega-i\eta} \right\}$$

Vertex corrections and gauge invariance

Herrmann, Friman and Noremberg 93; Chanfray and Schuck 93

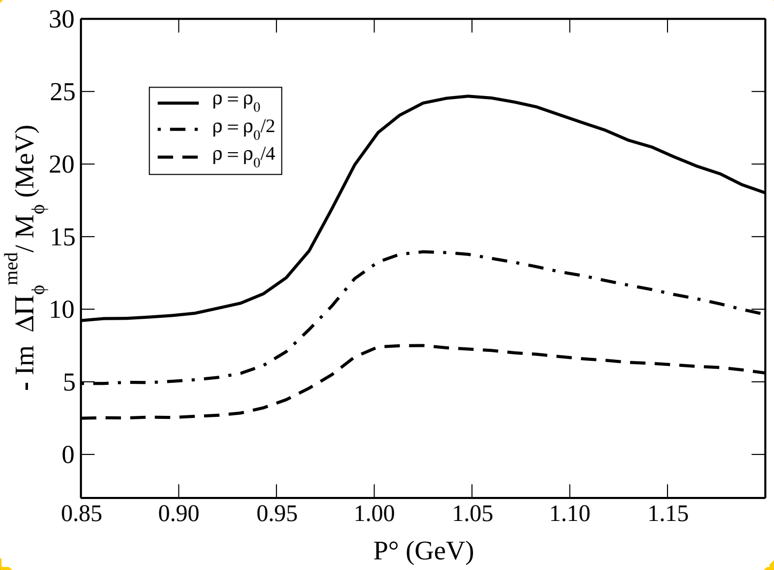
P- and *S*-wave kaon selfenergy insertions and realted vertex corrections:

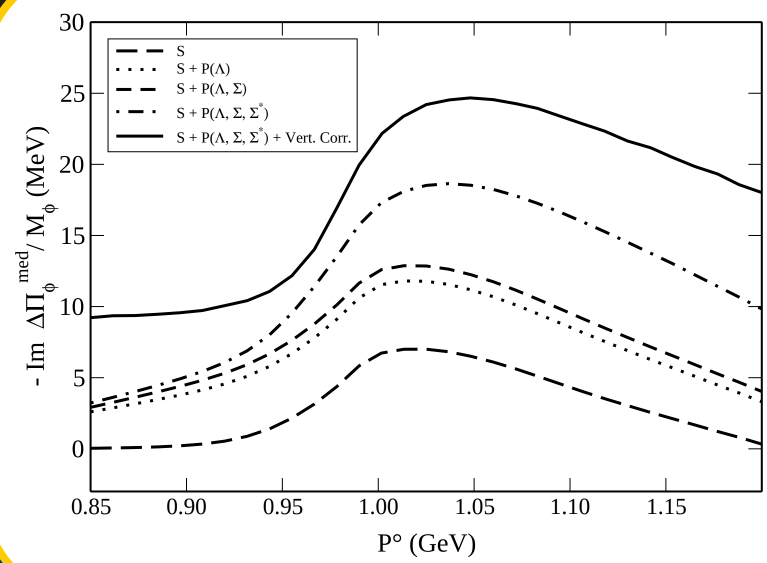




- (a) included by using the renormalized kaon & antikaon propagators
- (b-d) generated by vertex corrections
- Contact vertices: can be obtained by imposing W.I.

Results: ϕ mass and decay width in the nuclear medium





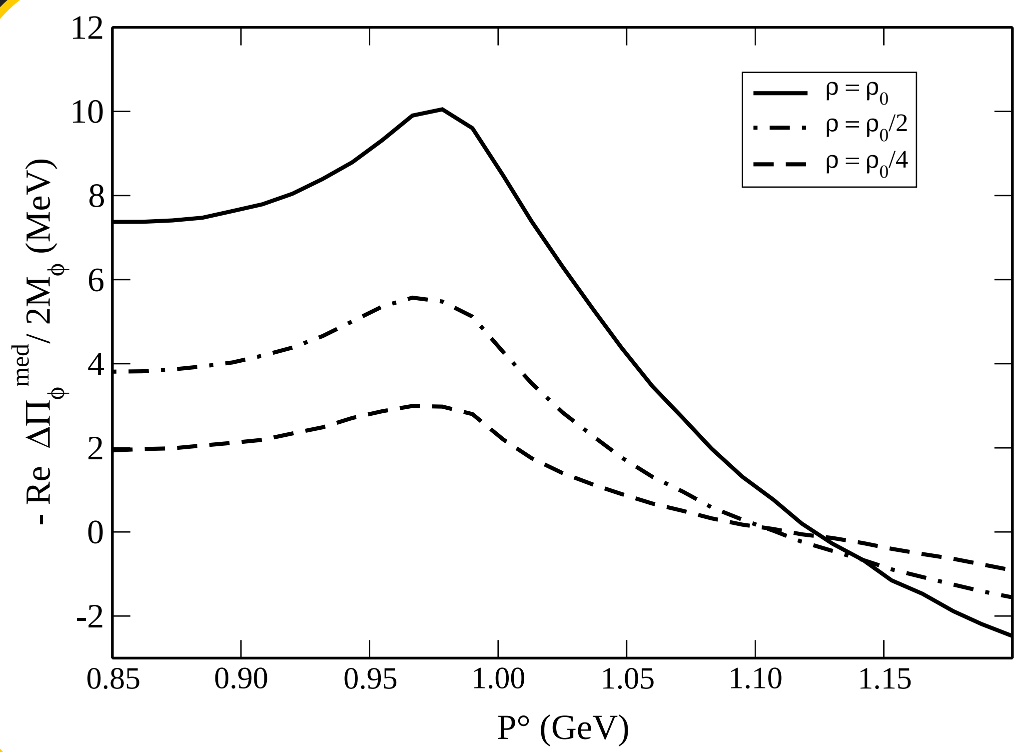
- ϕ width grows considerably with the density: $\Gamma_\phi \approx 30$ MeV, $\rho=\rho_0$

  F. Klingl, T. Waas and W. Weise, Phys. Lett. B 431 (1998) 254;

  E. Oset and A. Ramos, Nucl. Phys. A 679 (2001) 616

- Sizeable energy dependence due to the $\phi \to \bar{K}\, \Sigma^* h$ channel (thres. ~940 MeV)
- $\bar{K}$ *S*-wave: mildly attractive contribution, compensates partly *K* repulsion
- $\bar{K}$ *P*-wave: small contribution from Σ, sizeable from Λ and Σ^* excitations
- Vertex corrections: further enhancement of the total width

Results: ϕ mass and decay width in the nuclear medium (II)

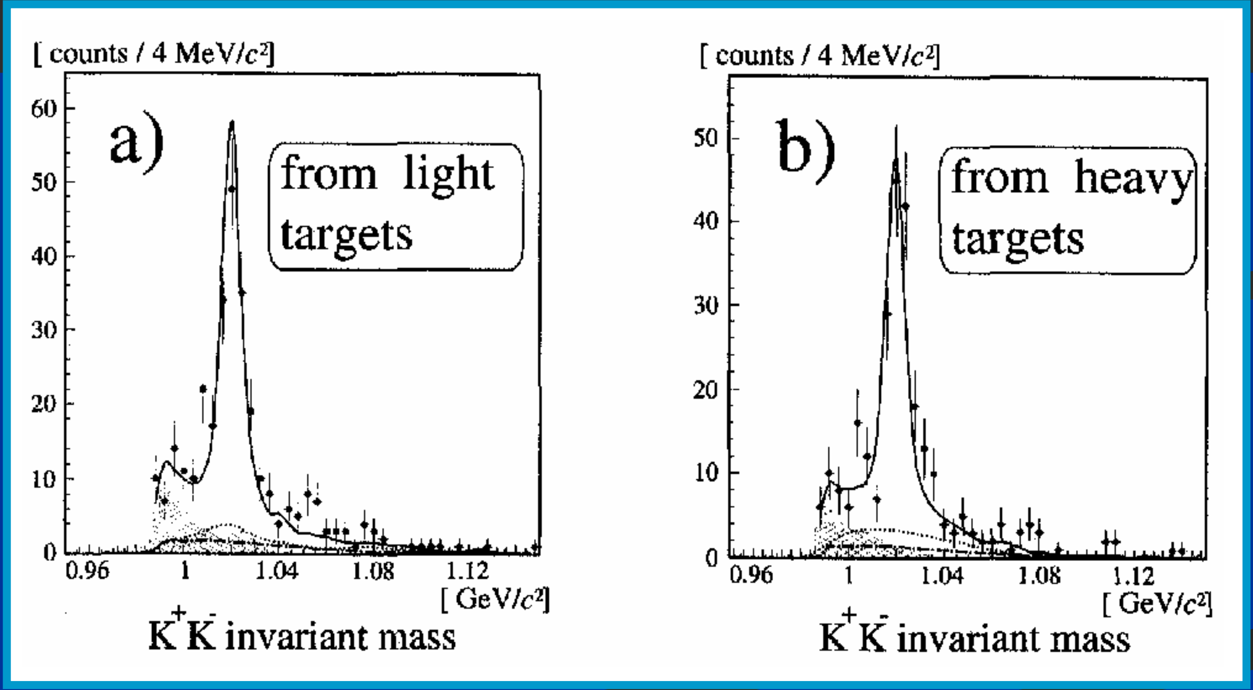


- Real part of ϕ selfenergy: very small, attractive up to 1.1 GeV
- ϕ mass change: ~(-8) MeV at $\rho=\rho_0$

Experimental information on ϕ properties in the nuclear medium

Several experimental proposals to observe changes in the ϕ properties in a nuclear medium:

- HIC's (*p-A, A-A* collisions)
- $\pi^- p \to \phi N$
- $\gamma N \to \phi N$



- Results from *p-A* reaction: *KEK-PS E325, K. Ozawa et al., Nucl. Phys. A 698 (2002) 535c*

Experimental information on ϕ properties in the nuclear medium

- Results from *p-A* reaction: ***KEK-PS E325,*** *K. Ozawa et al., Nucl. Phys. A 698 (2002) 535c*
- HIC's $^{28}Si + ^{196}Au$: ***BNL-AGS E802,*** *Y. Akiba et al., Phys. Rev. Lett. 96 (1996) 2021*

  Au + Au: ***PHENIX Col.,*** *Adler et al., nucl-ex/0410012*
- $\gamma A \rightarrow K^+K^-X$: ***LEPS,*** *T. Ishikawa et al., Phys. Lett. B608 (2005) 215*

→ *Medium effects on the mass or decay width of the ϕ meson are difficult to observe*

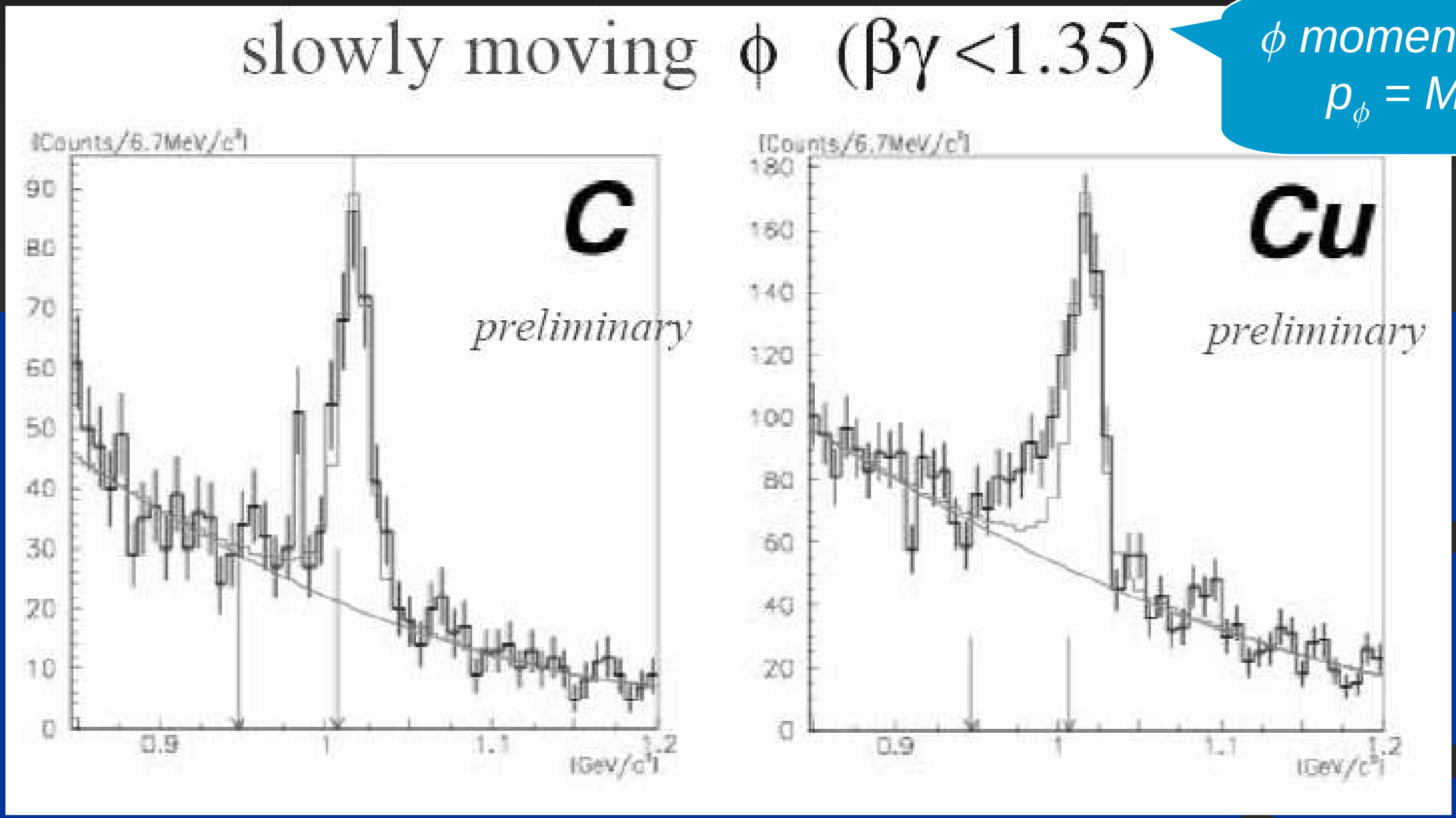
Problems:

- Long ϕ lifetime: ϕ decays outside the nuclear medium
- ϕ is produced with high P_ϕ
- Kinematical cuts to isolate small-P_ϕ events
  → poor statistics
- Distortion in K^+K^- distribution (Coulomb interaction may bind K^- in nucleus)

P. Muhlich, T. Falter, C. Greiner, J. Lehr, M. Post and U. Mosel, Phys. Rev. C 67 (2003) 024605

Dilepton spectrum from *p-A* reaction: *KEK-PS E325,*

presented at Chiral'05, 16 Feb 2005, RIKEN, Japan



ϕ momentum cut
$p_\phi = M_\phi \beta \gamma$

borrowed from S. Yokkaichi

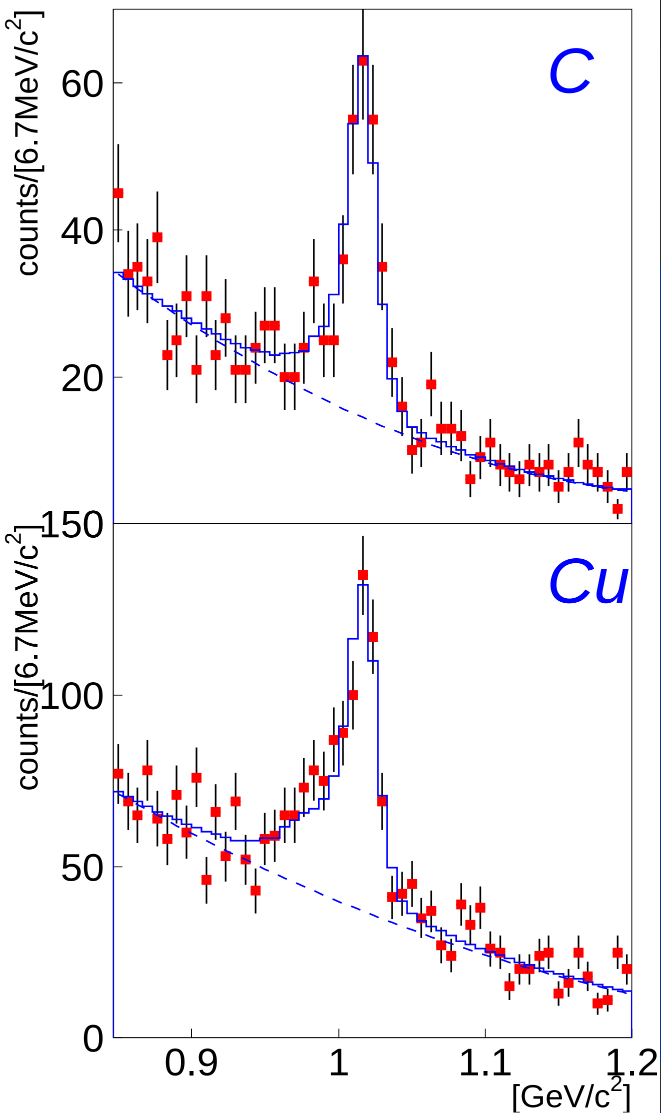
- Toy model with -16% mass shift at ρ_0 . Also $\Gamma_\phi(\rho) = (1+ 6\, \rho/\rho_0)\, \Gamma_\phi^{vac}$ is used in analysis to understand *dilepton yield excess*
- If only $\Delta\Gamma_\phi$, *symmetric effect* expected

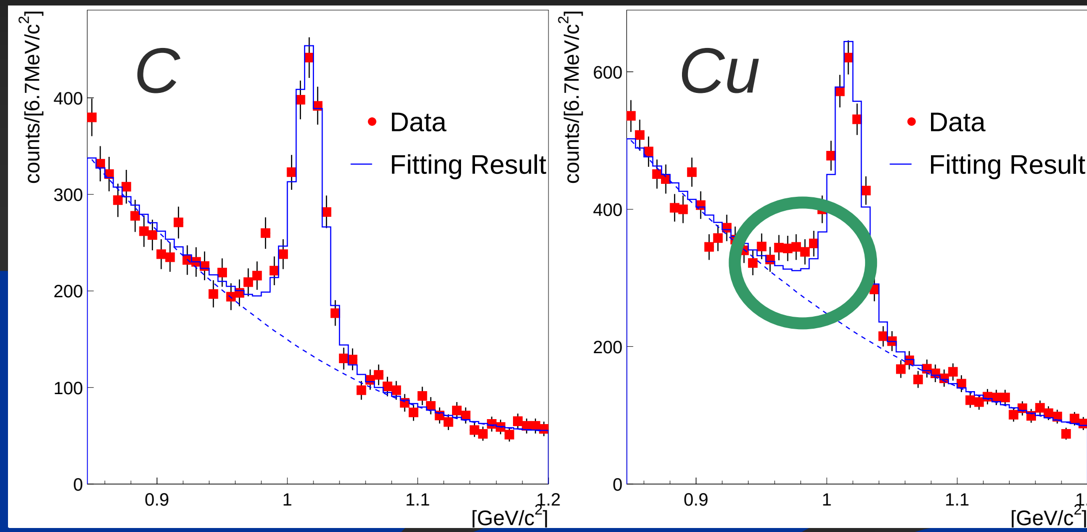
K^+K^- analysis on going…

Dilepton spectrum from *p-A* reaction: *KEK-PS E325,*

presented at QM '05, Aug 4-9, Budapest

βγ<1.25 (Slow)





borrowed from R. Muto

- Low energy tail cannot be fit (bkgnd + BW)
- $M_\phi(\rho) = (1\text{- }0.04\ \rho/\rho_0)\ M_\phi^{vac}$ ⟶ $\Delta M_\phi(\rho_0) \approx$ -40 MeV
- $\Gamma_\phi(\rho) = (1\text{+ }10\ \rho/\rho_0)\ \Gamma_\phi^{vac}$ ⟶ $\Gamma_\phi(\rho) \approx$ 44 MeV
- No momentum dependence ($p_\phi \sim$ 2 GeV)

$M_\phi(\rho)$ *Hatsuda et al.;* $\Gamma_\phi(\rho)$ *Weise et al.*

Study of inclusive nuclear ϕ photoproduction

Proposal: observation of loss of ϕ flux due to nuclear effects and its *A* dependence

- No need to cut ϕ phase space → better statistics
- *A* dependence of ϕ flux can be related to the ϕ decay width in the nuclear medium

But: Most of the produced ϕ's carry a high momentum

Extension of our model for finite P_ϕ

Experiment:

Spring8/Osaka **LEPS**

(γ, ϕ) with $E_\gamma \in [1.5\text{-}2.4]$ GeV

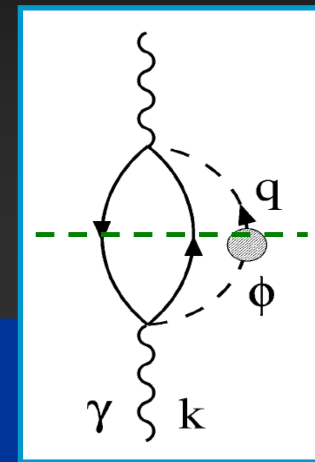
$P_\phi \sim 1.8$ GeV

Study of inclusive nuclear ϕ photoproduction

ϕ flux and ϕ decay width:

$$\frac{\Gamma_\phi}{2} = -\mathrm{Im}V_{opt} = -\mathrm{Im}\frac{\Pi_\phi}{2\omega} \quad \Rightarrow \quad \Gamma_\phi = -\frac{\mathrm{Im}\Pi_\phi}{\omega} \equiv \frac{dP}{dt}$$

$$\frac{dP}{dl} = \frac{dP}{v\,dt} = \frac{dP}{\frac{P_\phi}{\omega}dt} = -\frac{\mathrm{Im}\Pi_\phi}{P_\phi}$$



Nuclear cross section for inclusive nuclear ϕ photoproduction:

$$\frac{d\sigma_A}{d\Omega} = \int d^3\vec{r}\rho(r)\frac{d\sigma}{d\Omega}e^{-\int_0^\infty dl\,\frac{-1}{P}\mathrm{Im}\Pi_\phi(P^0,P;\rho(r'))}$$

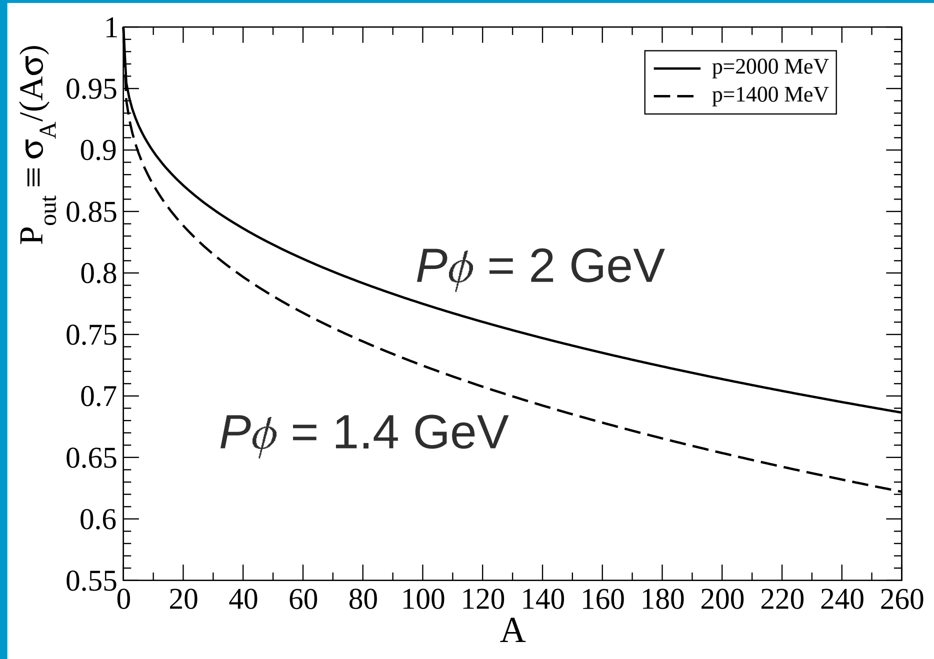
Absorption factor

ϕ survival probability:

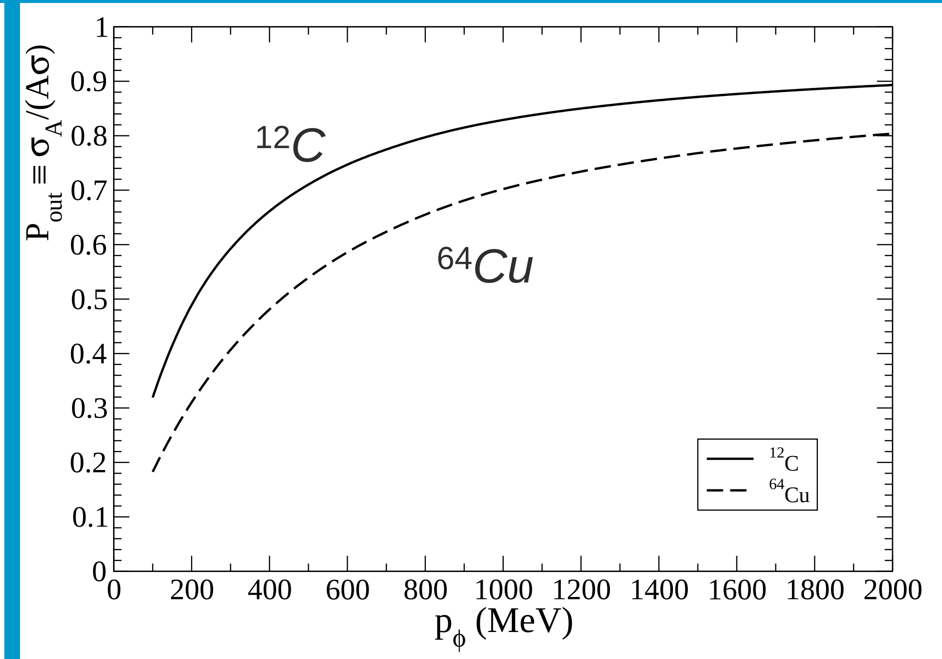
$$\mathcal{P}_{out} \equiv \frac{\sigma_A}{A\sigma} = \frac{1}{A}\int d^3\vec{r}\rho(r)\ e^{\int_0^\infty dl\,\frac{1}{P}\mathrm{Im}\Pi_\phi(P^0,P;\rho(r'))}$$

Inclusive nuclear ϕ photoproduction: results

A dependence



$P\phi$ dependence



- Clear loss of ϕ flux: enhanced effect for small P_ϕ and heavy nuclei
- E_γ = 1.6 GeV $\rightarrow$ P_ϕ $\approx$ 1000 MeV in fwd direction $\longrightarrow$ P_{out} ~ 0.65 for ^{64}Cu, and smaller for heavier nuclei

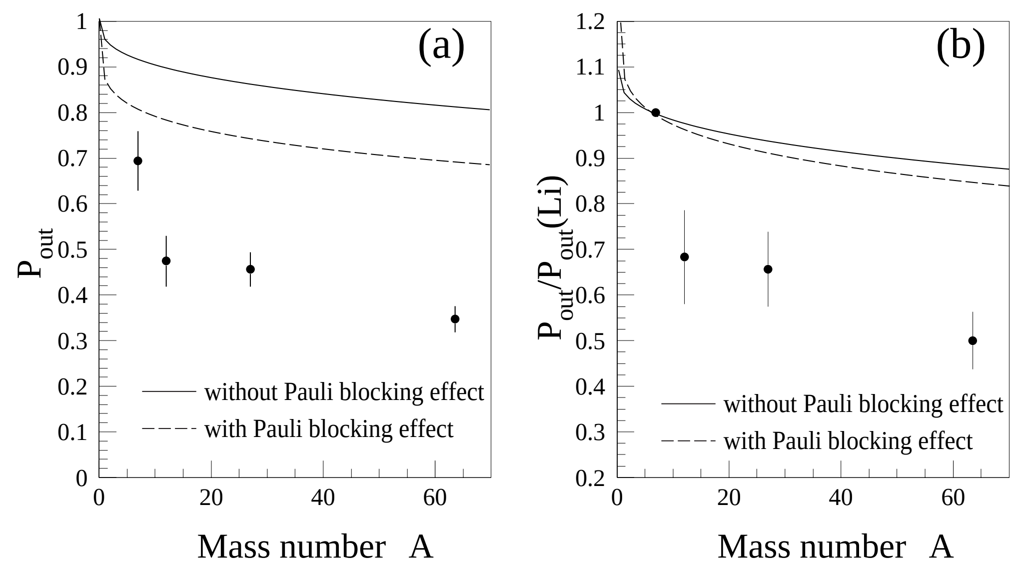
Inclusive nuclear ϕ photoproduction: experimental results

LEPS Collaboration,

T. Ishikawa et al.,

Phys. Lett. B608 (2005) 215,

nucl-ex/0411016



- Separation of the coherent ϕ photoproduction is important, particularly for light nuclei
- Stronger effect than theoretically predicted
- Calculation agrees with A-dependence (normalize to C)
- Other possible sources of ϕN interactions (further flux reduction)

Ex: $\phi \rightarrow 3\pi$ (pion selfenergy!), quasi-elastic collisions

ω meson: Outline

(Recent) experimental information on the ω meson in-medium decays

Overview of some theoretical work

ω meson in the medium: experimental information

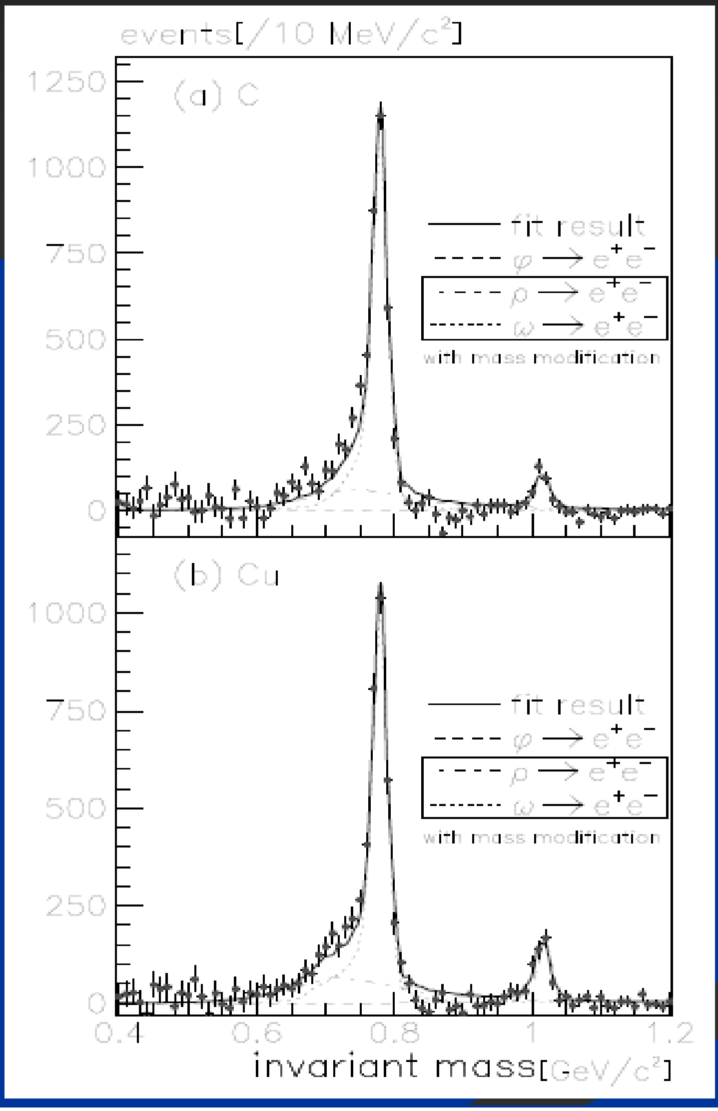
- Very small width in vacuum, mostly from 3π decay
- Appears overlapped with the ρ meson in the mass spectrum
- Several theoretical calculations predict *sizable changes* in mass / decay width at finite ρ or T
- Current experiments search for medium modifications in *mass spectrum observable*

Recent experimental results:

- *KEK-PS E325: p-A* reaction + $\rho/\omega \to e^+e^-$ decay
- CB-TAPS/ELSA Col. @ Bonn: nuclear ω photoproduction + $\omega \to \pi^0 \gamma$ decay

ω meson in the medium: experimental information

- *KEK-PS E325: p-A* reaction + $\omega \rightarrow e^+e^-$ decay *M. Naruki et al., nucl-ex/0504016*



- 50 times 2001 statistics
- e^+e^- mass resolution 8 MeV (ρ/ω) and 10 MeV (ϕ)
- Yield excess below ω mass:

$M_V(\rho)/M_V = 1 - k\ \rho/\rho_0$, $k \approx 0.10$ <u>*from fit*</u>

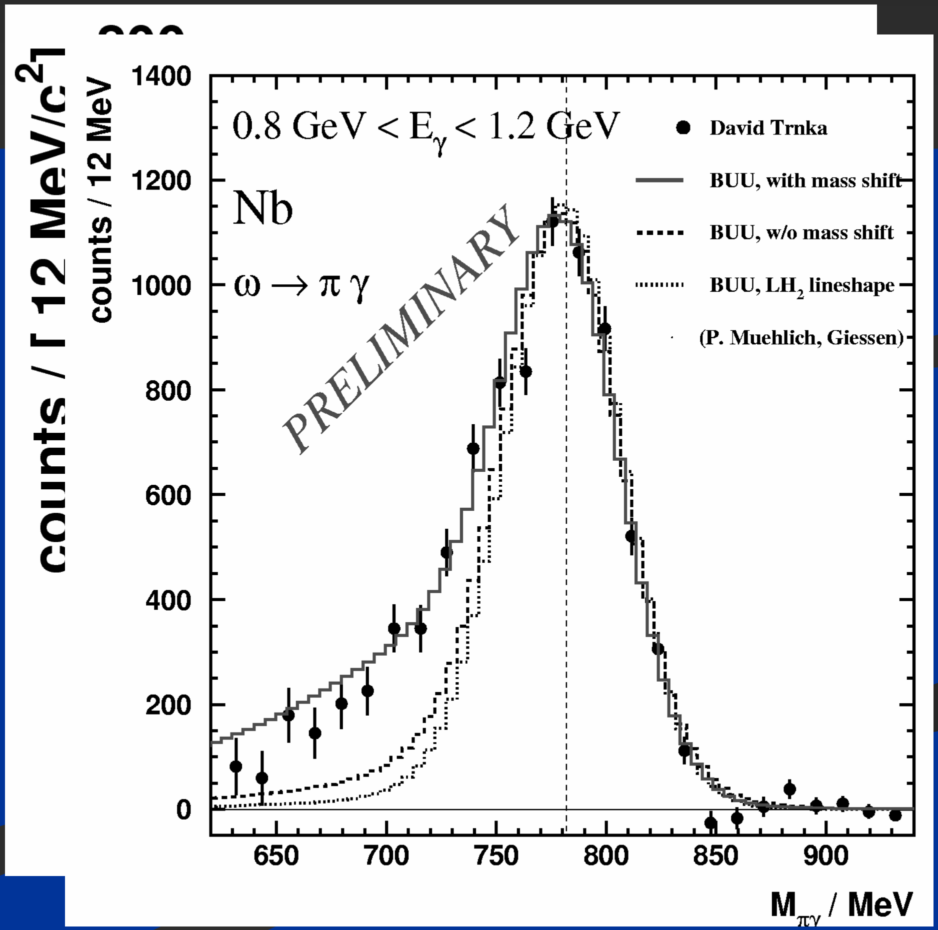
(k = 0.10-0.22, Hatsuda, Lee, Shiomi '95)

- <u>No broadening is assumed</u>
- Actually, <u>no broadening is favoured</u> in the analysis

ω meson in the medium: experimental information

- CB-TAPS@ELSA Col.: nuclear ω photoproduction + $\omega \to \pi^0 \gamma$ decay

- $\pi^0 \gamma$ decay: much suppressed for ρ meson (10^{-2}) ⟶ no overlap
- Sizable enhancement of spectrum below M_ω
- Effect vanishes when increasing p_ω cuts
- Width dominated by exp. resolution (Γ_ω < 55 MeV at estimated $\rho = 0.6\rho_0$)



BUU transport calculation incl. FSI, collisional broadening and explicit ΔM_ω proportional to density (-16% at ρ_0)

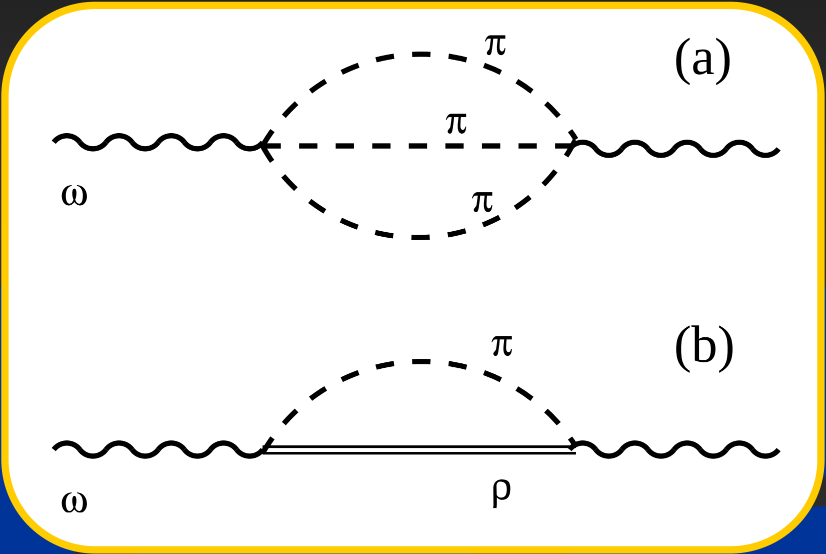
P. Mühlich et al., Eur. Phys. J. A20 (2004) 499

borowed from V. Metag

ω meson in the medium: theoretical approaches

A simple calculation in a selfenergy approach

$$\mathcal{L}^{(3)}_{V\Phi} = \frac{i\,h}{4f_\pi^3}\epsilon^{\mu\nu\alpha\beta}\mathrm{tr}(V_\mu\partial_\nu\Phi\partial_\alpha\Phi\partial_\beta\Phi) + \frac{g_{VVP}}{4f_\pi}\epsilon^{\mu\nu\alpha\beta}\mathrm{tr}(\partial_\mu V_\nu V_\alpha\partial_\beta\Phi)\ ,$$



$\rho\pi$ decay is about 90% of $\Gamma(\omega\to 3\pi)$

(from $\phi \longrightarrow (\omega) \longrightarrow 3\pi$ and radiative decays)

P. Jain et al., Phys. Rev. D37 (1988) 3252; F. Klingl et al., Z. Phys. A356 (1996) 193

Medium effects on intermediate mesons:

- 3π: plenty of phase space, pion attraction will not make a strong effect
- $\rho\pi$: not open at the physical ρ mass, only the *low energy ρ tail* is explored ($E \sim 500$ MeV, $p \sim 200$ MeV)

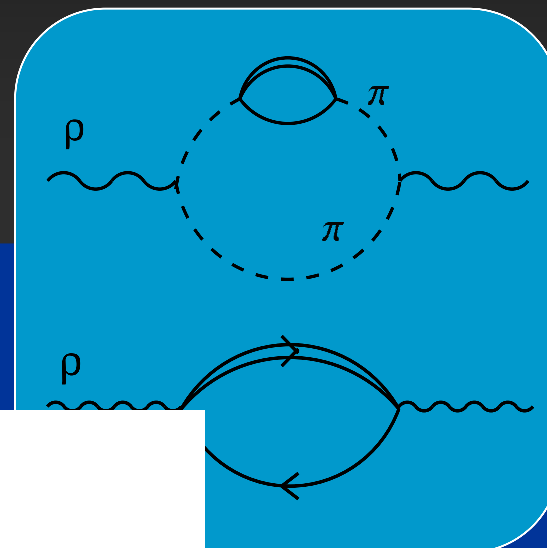
ρ spectral function enhanced in this region at finite nuclear density

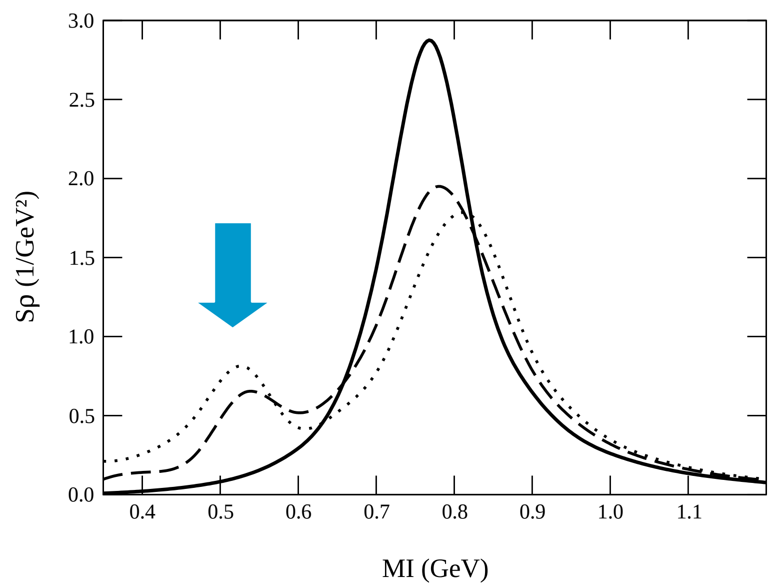
ω meson in the medium: theoretical approaches

A simple calculation in a selfenergy approach

Several in-medium mechanisms could spread ρ spectral density to lower energies:

- π selfenergy *(ph, Δh)*
- ρ coupling to *ph*, Δh states (for $p_\rho \neq 0$)
- Excitation of *Rh* states (ex. $N^*(1520)$,...)





D.Cabrera et al., Nucl. Phys. A705 (2002) 90

at rest:

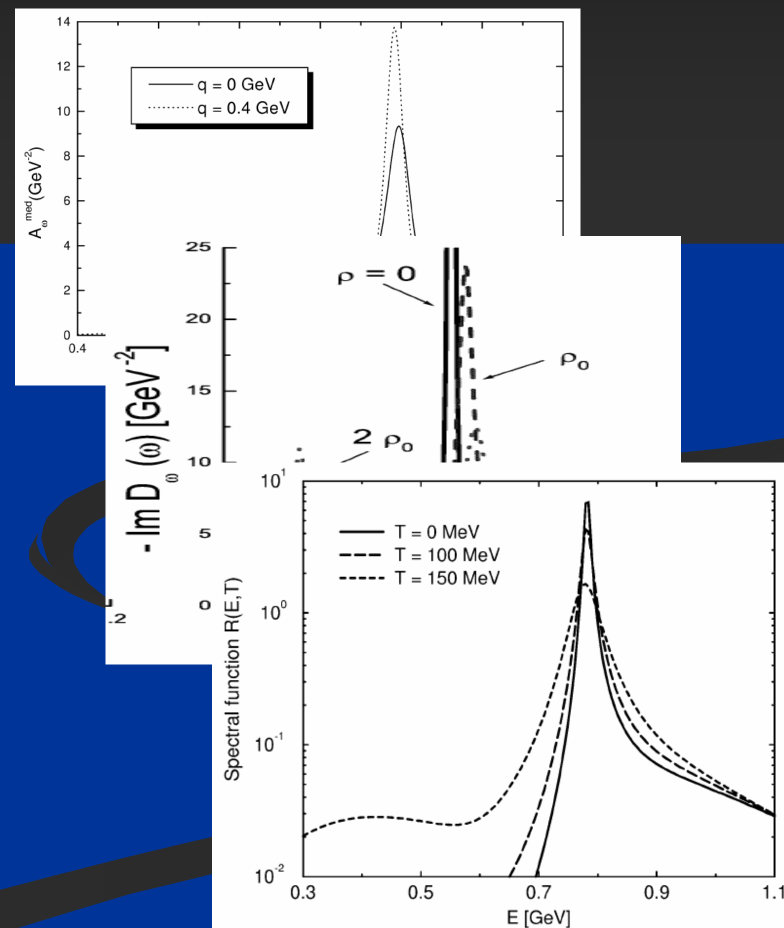
(Γ_ω^{vac} = 8.49 MeV)

excitation!!)

ω meson in the medium: theoretical approaches

Many other mechanisms have been studied

- $\omega N \rightarrow \pi N$, $\omega N \rightarrow \rho N \rightarrow [\pi\pi]N$ in a Chiral SU(3) Lagrangian approach: $\Delta\Gamma_{\omega} \approx$ 40 MeV! *F. Klingl et al. Nucl. Phys. A624 (1997) 527; A650 (1999) 299*
- ω coupling to several *Rh* states *(N*(1520)h, N*(1650)h, ...)* *M. Post et al. Nucl. Phys. A688 (2001)808; M. Lutz et al Nucl. Phys. A706 (2002) 431*
- Self-consistent determination of ρ and ω spectral functions *F. Riek et al., Nucl. Phys. A740 (2004) 287*
- Finite *T* effects (ex. $\omega\pi \rightarrow \pi\pi$, thermally excited pions) *R. Rapp, Phys. Rev. C63 (2001) 054907; R. Schneider et al., Phys. Lett. B515 (2001) 89; A. Martell et al., Phys. Rev. C69 (2004) 065206*
- QCD sum rules calculations *S. Zschocke et al., Phys. Lett. B562 (2993) 57*



ω meson in the medium: theo + exp

Γ_ω expected to increase ≈ one order of magnitude, the ω still keeping its resonant shape as a quasiparticle in the nuclear medium

This should be observable as a (A-dependent) clear loss of ω flux in a nuclear photoproduction experiment...

...well suited to provide COMPLEMENTARY information to the measure of the mass spectrum observable in vector meson decays

What is needed (from ϕ experience) ?

- Good control of *coherent production*
- Reliable calculations of ω properties at finite p_ω

If some effect is observed...

- Clear evidence of medium effects on the ω meson (Γ_ω)
- Test of ρ and *p* dependence of calculated ω nuclear potentials

Conclusions

- Much work has been carried out regarding the properties of vector mesons in dense and hot matter

- Narrow vector mesons (particularly ϕ) have recieved less attention, but very exciting experimental results have been found recently in production reactions in nuclei

ϕ meson mass and decay width in a nuclear medium

- Model calculation based on (anti-)kaon selfenergies
- ϕ decay width increases considerably in nuclear matter (6-8 Γ_{ϕ}^{free} at ρ_0)
- Very small change in the ϕ mass
- Very recent analysis from *p-A* dilepton spectrum from *KEK-PS* shows some nuclear medium effect

Conclusions

Inclusive nuclear ϕ photoproduction: *A* dependence

- *A* dependence of loss of ϕ flux can be related to the in-medium ϕ decay width
- Clear deviation from unity in the calculated ϕ survival probability indicates a loss of ϕ flux due to nuclear medium effects
- Experimental results from LEPS find a reduction in the survival probability, *stronger effect than calculated*

ω meson properties

- Sizable effects theoretically estimated
- Some effect experimentally observed in nuclear photoproduction + $\pi^0\,\gamma$ decay by CB-TAPS/ELSA
- We suggest that measurement of loss of ω flux (and *A*-dependence) could provide complementary information (Γ_ω)

Backup slides

Outlook and work in progress

Inclusive nuclear ϕ photoproduction: *A* dependence

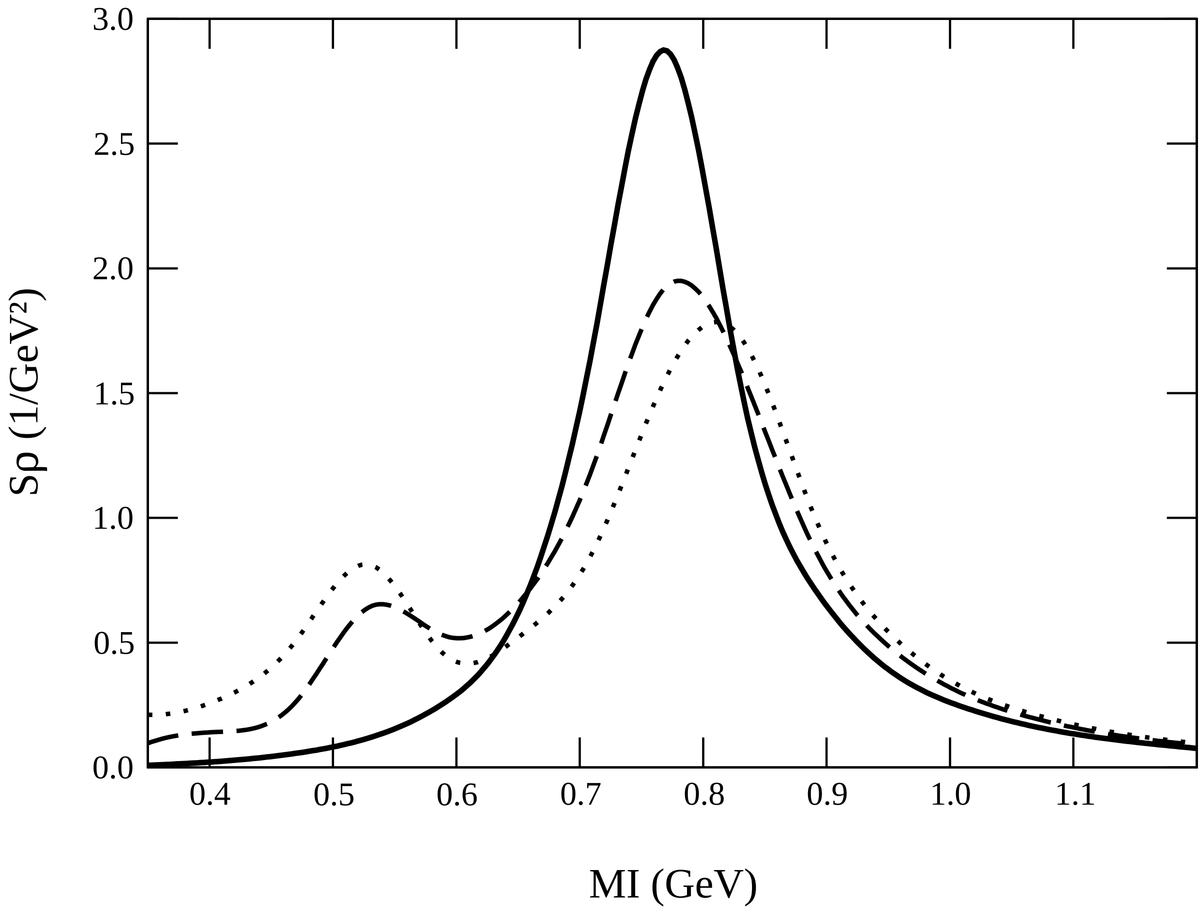
- Calculate *A* dependence of loss of ϕ flux for different kaon-antikaon potentials (shallow-deep) $\longrightarrow$ study sensitivity of P_{out}
- Study other possible effects leading to a flux reduction: $\phi \to 3\pi$ (small), quasi-elastic ϕN collisions (forward acceptance)
- Extend the model for finite temperature (application to HIC)

ω meson selfenergy

- Complete selfenergy calculation including pion cloud modifications, ρ selfenergy and coupling of ρ, ω to baryonic resonances (and finite T)
- Subthreshold coupling to $\bar{K}K$ $\longrightarrow$ *additional open channels in the nuclear medium (+ 5 MeV)*

ρ spectral function in nuclear matter (ρ at rest)

D. Cabrera, E. Oset and M.J. Vicente Vacas, Nucl Phys. A705 (2002) 90

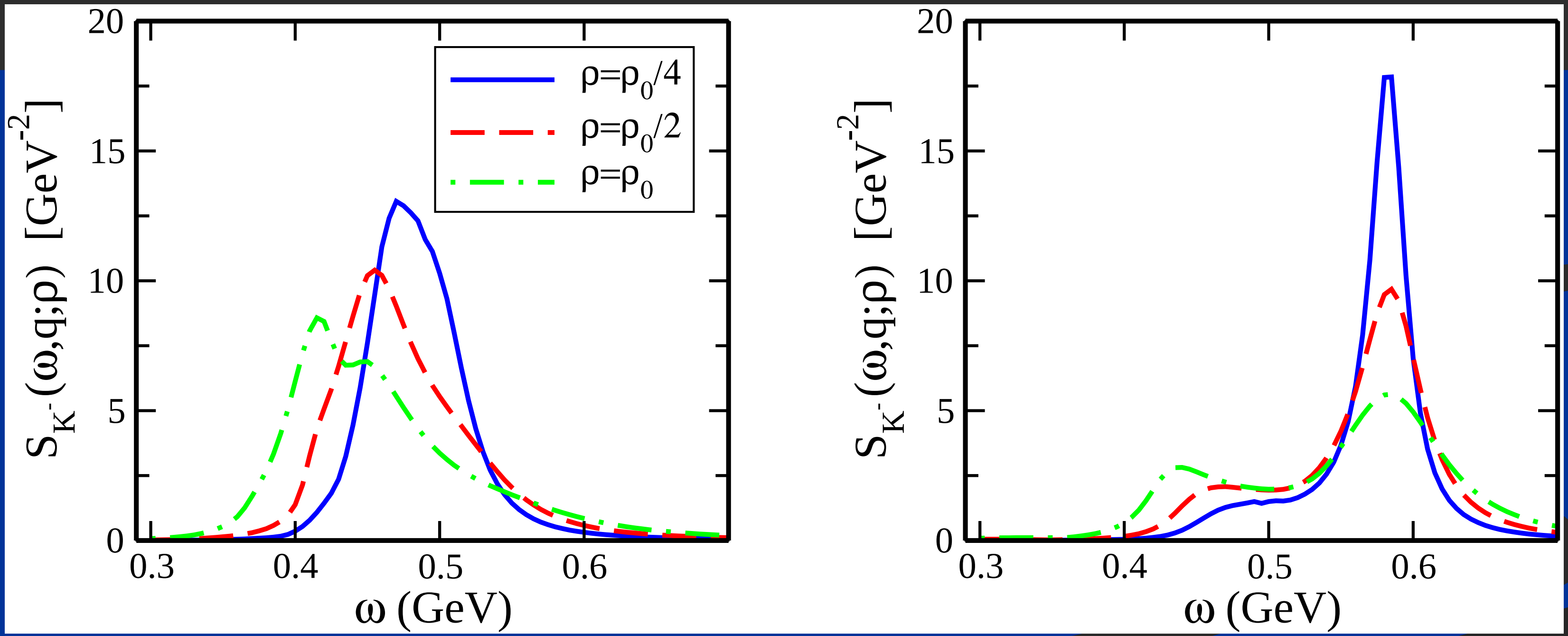


$$\phi \rightarrow (\omega) \rightarrow 3\pi$$

$$\phi \rightarrow (\omega) \rightarrow \rho\pi$$

Antikaon spectral function for several nuclear densities

A. Ramos and E. Oset, Nucl.Phys. A 671 (2000) 481



zero momentum

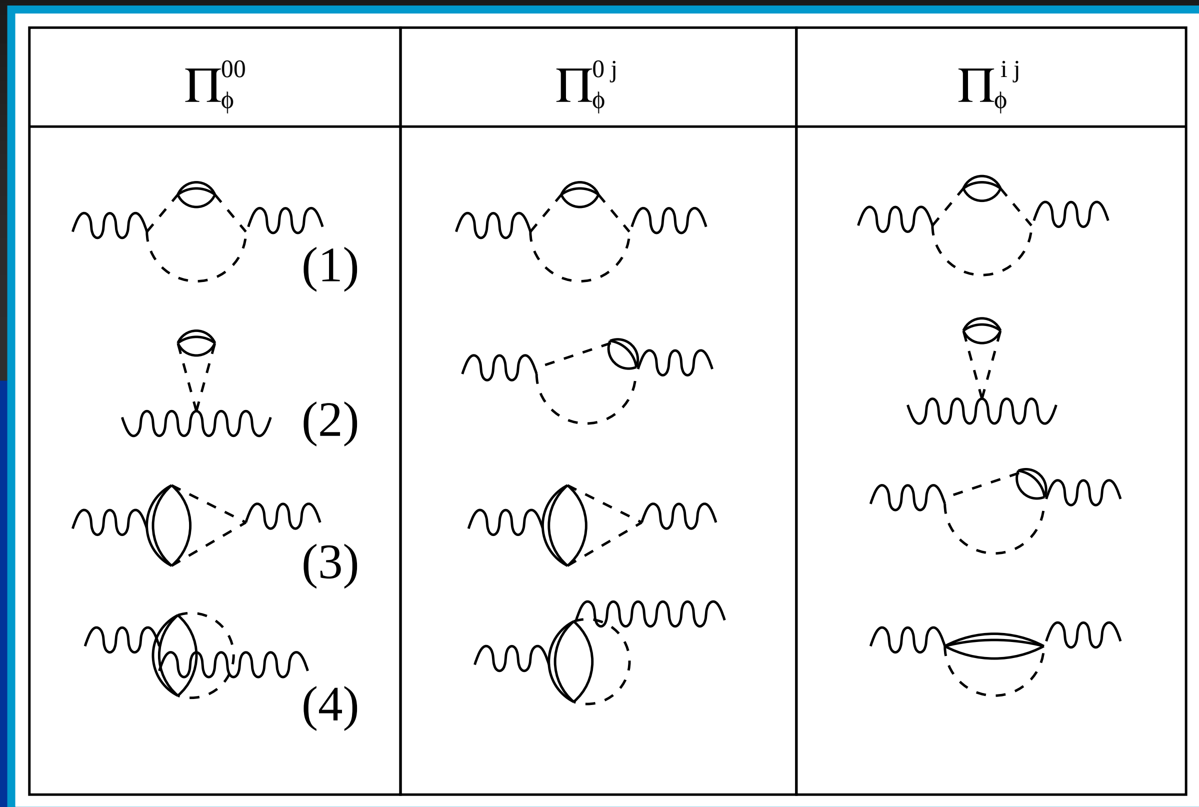
q=300 MeV

ϕ selfenergy from kaon loop and tadpole diagrams, in terms of the spectral functions of the kaon propagators

$$\Pi_\phi(P^0;\rho) = 2g_\phi^2 \frac{1}{2\pi^2}\frac{4}{3}\int_0^\infty dq\,\vec{q}^{\,2}\Big\{\frac{\vec{q}^{\,2}}{\widetilde{\omega}(q)}\int_0^\infty d\omega\,\frac{S_{\bar{K}}(\omega,|\vec{q}|;\rho)\,(\omega+\widetilde{\omega}(q))}{(P^0)^2-(\omega+\widetilde{\omega}(q))^2+i\epsilon}$$

$$+\ \frac{3}{4}\Big[\int_0^\infty d\omega S_{\bar{K}}(\omega,|\vec{q}|;\rho)+\frac{1}{2\widetilde{\omega}(q)}\Big]\Big\}$$

Vertex corrections and gauge invariance (II)



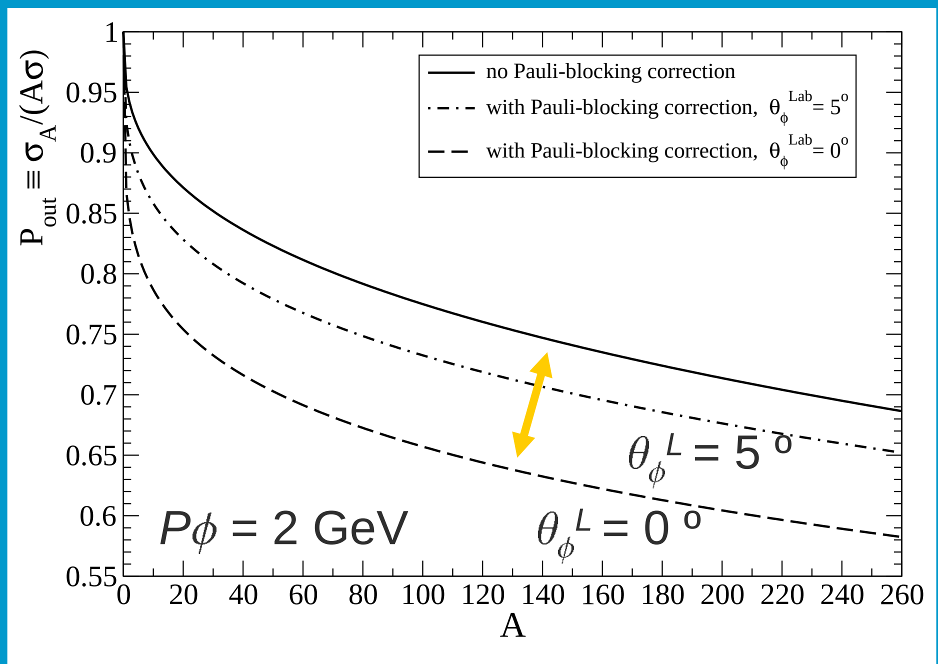
Detailed analysis of necessary diagrams to satisfy gauge invariance in a non-realtivistic approximation of vertices involving baryons and baryon propagators

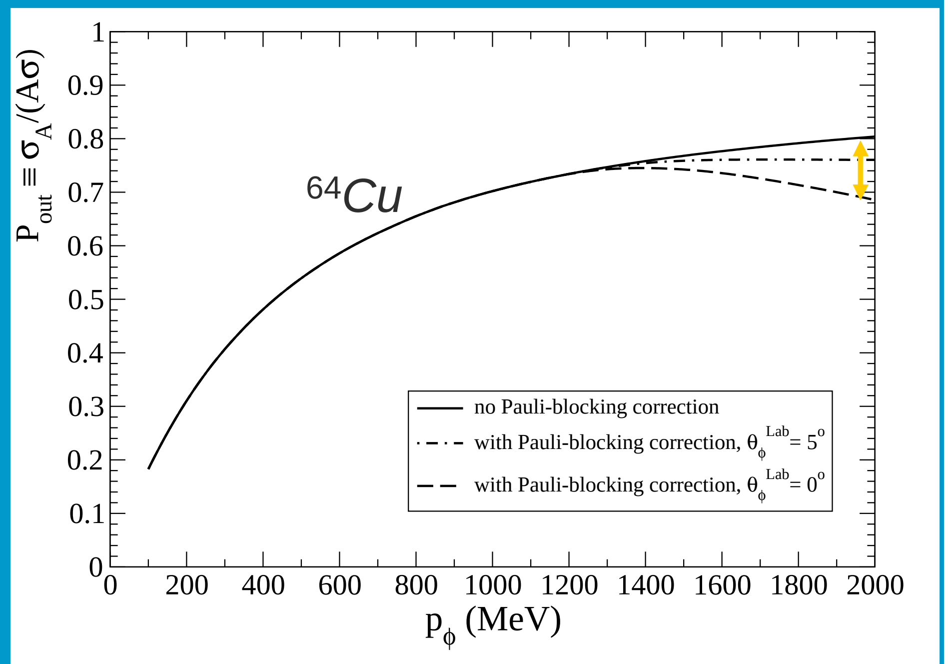
$$q_\mu \Pi_\phi^{\mu\nu} = 0 \quad \Longleftrightarrow \quad \begin{array}{l} q^0 \Pi_\phi^{00} = 0 \leftrightarrow \Pi_\phi^{00} \\ q^0 \Pi_\phi^{i0} = 0 \leftrightarrow \Pi_\phi^{i0} = 0 \\ q^0 \Pi_\phi^{0j} = 0 \leftrightarrow \Pi_\phi^{0j} = 0 \end{array}$$

(ϕ at rest in n.m.)

Inclusive nuclear ϕ photoproduction: results

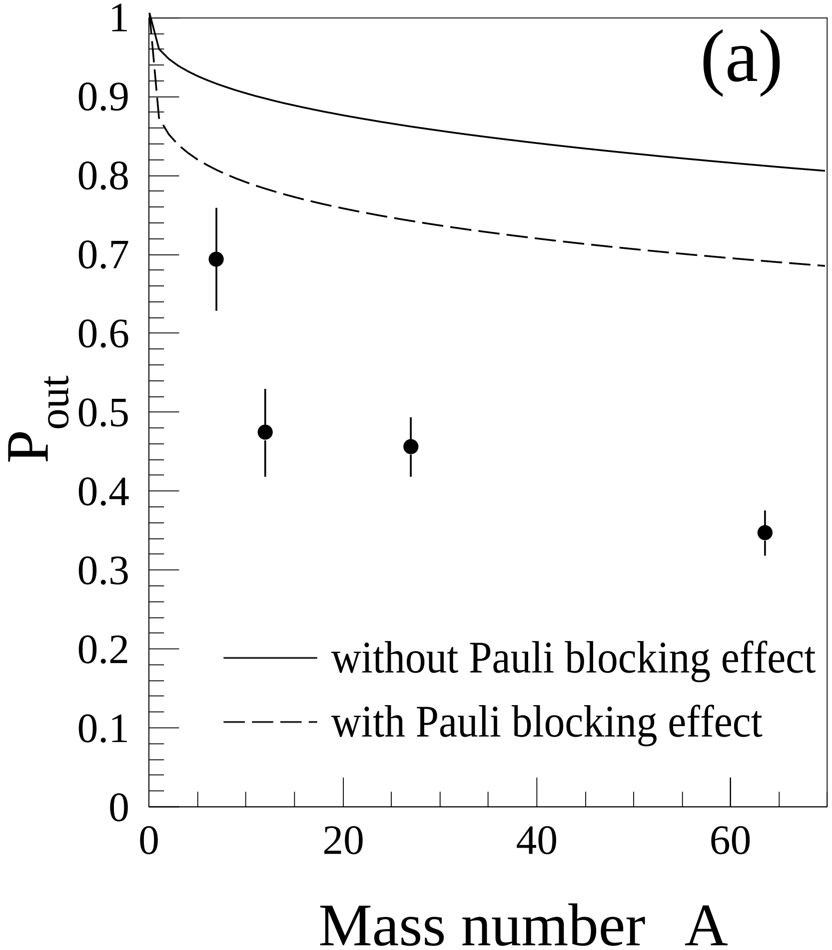
Other nuclear effects: Pauli blocking and Fermi motion

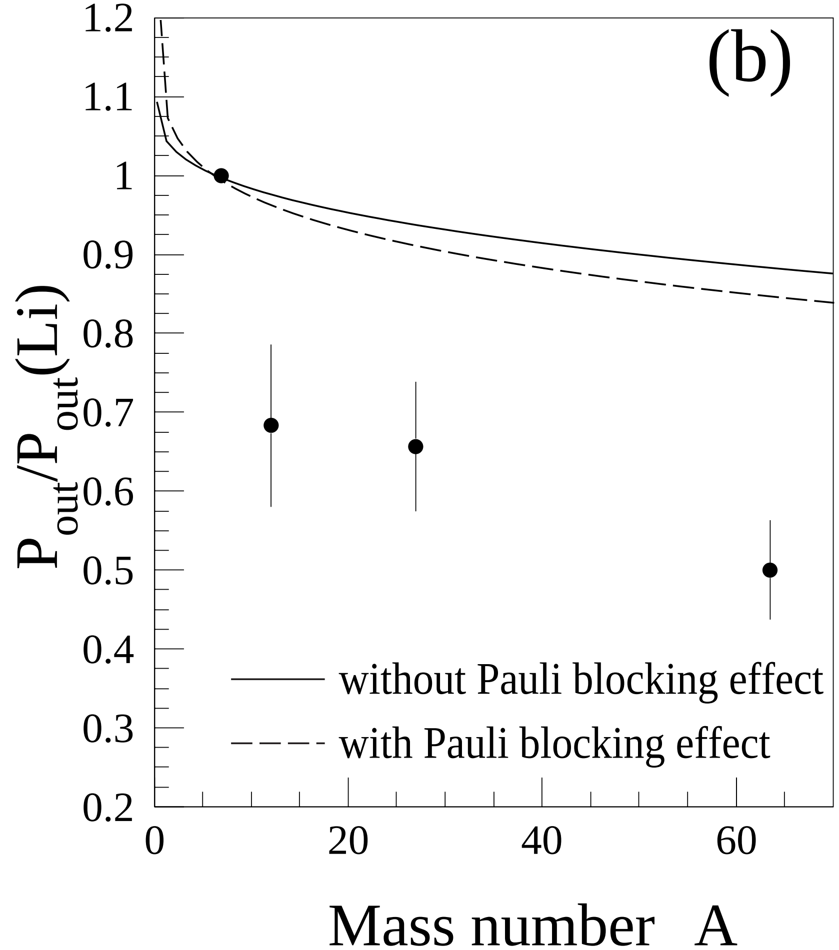




- Pauli blocking of the final nucleon is important for high P_ϕ (small momentum transfer)
- ϕ photoproduction is forward peaked, thus actual effect is to be found somewhere in θ_ϕ^L < a few degrees

Inclusive nuclear ϕ photoproduction: experimental results





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

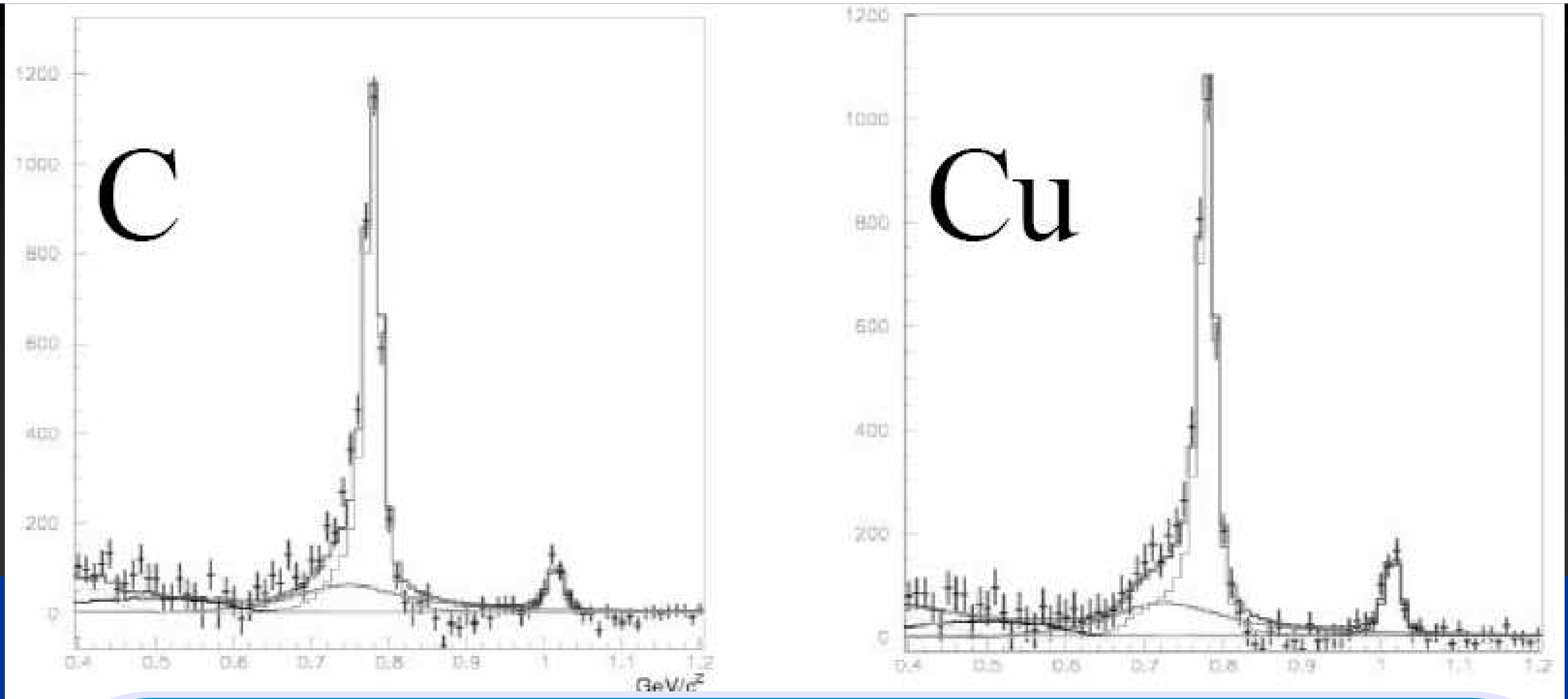
LEPS Collaboration

Toy model again : Width broadning of ϕ ?

- Many theoretical predeictions ...
  - Γ=22MeV, Δm=0 at $\rho=\rho_0$ (Oset et.al,2001)
  - Γ=30MeV, Δm=8MeV at $\rho=\rho_0$ (Cabrera et.al, 2003)
- Toy model like ρ&ω, including width (=decay prob.) change
- Inside-nucleus decay (=at $\rho > 0.5\ \rho_0$) probability for ϕ

	C	Cu
– natural width (Γ=4.4MeV)		
• all our acceptances	1 %	3%
• slow ($\beta\gamma < 1.35$)	2 %	6%
– Γ=30MeV at $\rho=\rho_0$		
• all	5 %	18%
• slow	9 %	32%
– Observation : N(excess)/(N(excess)+N(ϕ))		
• all	(9+-7) %	(13+-7)%
• slow	(15+-15) %	(25+-12)%

- $\Gamma^*/\Gamma_0 = 1+ 6\ \rho^*/\rho_0$
  4.4 *7~30MeV at $\rho=\rho_0$)
  - <u>no theoretical basis</u>



Results from experiments measuring mass spectrum observable show some medium effects are there, BUT interpretation in terms of ΔM_V and / or $\Delta\Gamma_V$ still difficult

- Sizable modifications are predicted
- ϕ, ω stay as quasiparticles in the medium