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Hadron width in nuclear matter

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Outline

- Short introduction
- In-medium spectral function of a hadron
- φ- mesons in nuclear matter
- Antiprotons in nuclear matter
- Discussion
- Conclusion

Modification of a hadron properties in baryon environment have been predicted within various theoretical approaches as:

- QCD sum rules
- chiral dynamics
- relativistic mean-field
- quark-meson coupling model

See K.Saito et al., arXiv:hep-ph/0506314 for a recent review

Embedded a hadron in baryon matter can change its mass and width.

This change is connected to:

- interaction of a hadron with surrounding baryonic medium
- in-medium change of quark condensates ?

The observation of this effect can be precursor phenomena of the transition of strongly interacting matter to the chirally symmetric phase.

Spectral function of a hadron in medium

In free space:

$$S(M) = (\Gamma_0/2) / [(M-M_0)^2 + (\Gamma_0/2)^2],$$

where Γ_0 and M_0 stand for a meson width and pole mass

$$\Sigma/2E = U_{opt} = \Re e U_{opt} + \Im m U_{opt}$$

Σ *is a self - energy,* E *is a meson energy*

In nuclear medium:

$$S(M) = [(\Gamma_0/2)+(\Gamma^*/2)] / \{(M-M_0+ M^*)^2 + [(\Gamma_0/2)+(\Gamma^*/2)]^2\}$$

Spectral function of a hadron in medium

$M^* = \Re eU(\rho);$ $\Gamma^*/2 = - \Im mU(\rho)$

$$S(M) = [\Gamma_0/2 - \Im mU]/\{[M - (M_0 + \Re eU)]^2 + (\Gamma_0/2 - \Im mU)^2\}$$

The real part of the nuclear optical potential yields a shift of the hadron mass pole while the imaginary part yields an additional width in medium

Note: $\Re eU > 0$ (K+) or $\Re eU < 0$ (K-), while $\Im mU < 0$;

AA vs γ(p)A

It is useful to explore the reaction with elementary probes since sizable - about 20 % - medium effects were predicted already at the density of ordinary nuclei

Spectral function of a hadron in medium

In-medium ***mass*** modification:

In AA: ρ meson (CERN SPS, RHIC)
K^- meson (GSI)

In γA and pA: K^+ meson (COSY)
ω meson (ELSA, KEK)
φ meson (KEK)

However, much less is known about the in-medium modification of hadron *width*

φ mesons in nuclear matter

$\Gamma_\varphi = 4.4$ MeV in free space

28 MeV $< \Gamma_\varphi <$ 50 MeV in medium

$\varphi \longrightarrow K^+K^-$ (BR ~ 50%)

- invariant mass K^+K^- distribution (Oset, 2001)
  strong distortion (Muehlich, Mosel, 2003)
- **alternative method to study** the imaginary part of φ nucleus potential - and thus **the φ width** in the nuclear medium - **by an attenuation measurements of the φ flux** in photonuclear reactions (D.Cabrera et al.,, 2004)
- valuable information can be obtained from the analysis of A-dependence of the φ production cross section

φ mesons in nuclear matter

SPRING - 8 experiment (Ishikawa, 2005)

$\gamma A \longrightarrow \varphi(K^+K^-)$

$E\gamma = 1.5 - 2.4$ GeV Be, C, Al, Cu

Strong dependence on the target mass number

A^α $\alpha = 0.72 \pm 0.07$ (incoherent production)

Statistics ~ 300 events / target

Data are published without absolute normalization

φ mesons in nuclear matter

Theoretical analysis:

- Chiral dynamics (Cabrera et al., 2003)
- BUU approach (Muehlich, Mosel, 2006)
- Optical model (Sibirtsev et al., 2006)

Underestimate the effect by a factor of 2

φ mesons in nuclear matter

It is useful to study also proton-nucleus collisions as a further source of information $(\overline{L}_{\varphi})^{pA} > (\overline{L}_{\varphi})^{\gamma A}$

KEK experiment E 325, $E_p = 12$ GeV (*Tabaru, 2006*)

$pA \longrightarrow \varphi X$ $\qquad$ $pA \longrightarrow \omega X$

***weak** φ distortion !*

$\alpha = 1.01 \pm 0.09 \quad (\varphi \longrightarrow K^+K^-)$

$\alpha = 0.94 \pm 0.05 \quad (\varphi \longrightarrow e^+e^-)$

$\alpha = 0.71 \pm 0.04 \quad (\omega \longrightarrow e^+e^-)$

φ mesons in nuclear matter

Anomalous A-dependence
of the φ–meson production from
nuclear targets is not still understood.

New theoretical and experimental
studies are required.

φ mesons in nuclear matter

ANKE - COSY experiment

M. Hartmann, Yu. Kiselev COSY Proposal #147.2; approved

pA ⟶ φX;

pA ⟶ K^+K^-X;

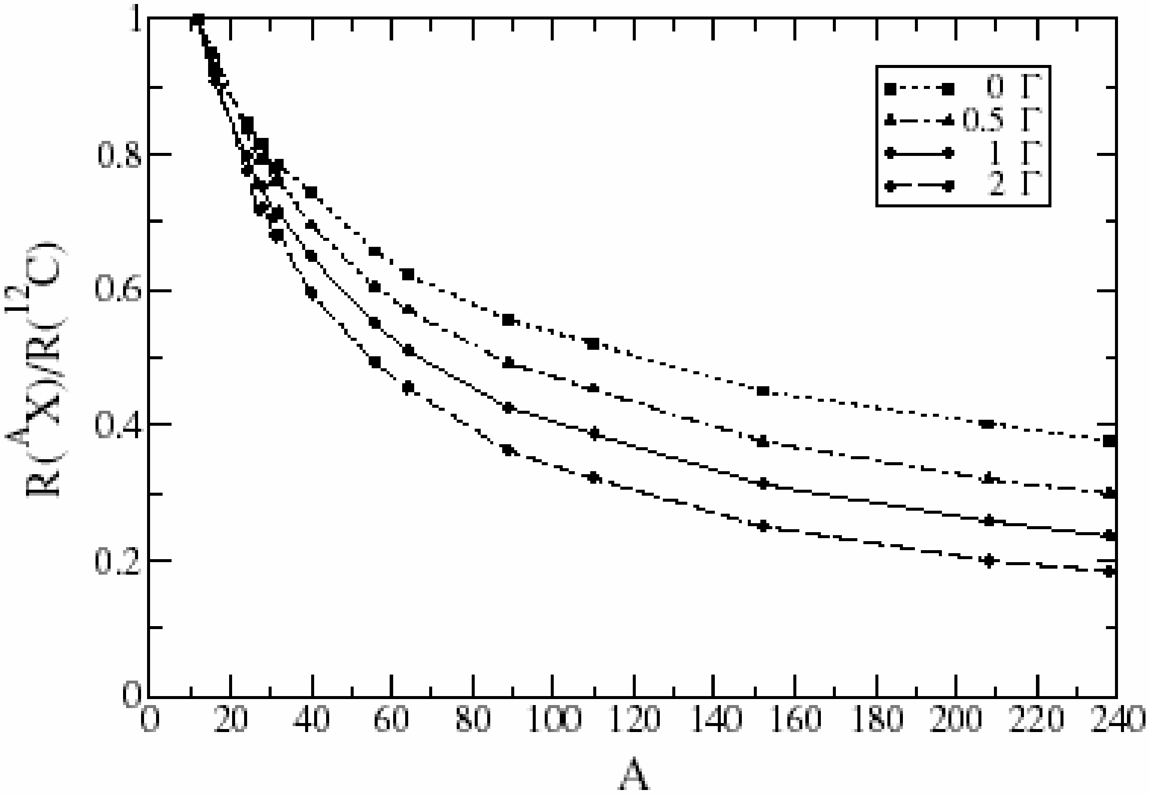
E_p = 2.83 GeV;

$$P = \exp(-\int_z^\infty \frac{d\vec{l}\,\Gamma^*(p_\varphi, \rho(r'))}{\beta_\varphi})$$

Γ* = -2 ℑmU; β_φ – velocity

Γ=24 MeV in the figure

(V.K. Magas et al, 2005)



φ mesons in nuclear matter

ANKE - COSY experiment

1.1 GeV/c < Pφ < 2.9 GeV/c (Ishikawa, Tabaru)
0.6 GeV/c < Pφ < 1.8 GeV/c (ANKE)

Absorption of the resonant and non-resonant
K^+K^- continuum in nuclear matter (ANKE)

φ mesons in nuclear matter

ANKE - COSY experiment

We intend to collect high statistics on light (C), medium (Ag) and heavy (Au) nuclei in wide momentum range 0.8 – 1.8 GeV/c and to obtain precise, absolutely normalized data on the φ production in proton-induced reactions.

The φ width in nuclear matter will be determined through the analysis of the A-dependence of the cross sections based on multiple scattering theory of Glauber.

The analysis of low momentum nonresonant K^+K^- production will permit us to determine the antikaon (K^-) nuclear potential which is important but still unsolved problem.

Antiprotons in nuclear matter

Experimental evidences for weak antiproton distortion in pA reactions:

- A. Vaisenberg et al., 1978
- T. Abbot et al., 1993
- Y. Sugaya et al., 1998
- I. Chemakin et al., 2001

$$P = \exp\left(-\int_z^{\infty} d\vec{l}\,\sigma_{hN}^{med}(p_h)\rho(r')\right)$$

$$\sigma_{hN}^{med} = \frac{\Gamma^*(p_h)}{\beta_h \rho(r')}$$

One can equivalently use the in-medium hN cross section for the description of hadron absorption in nuclear matter

Antiprotons in nuclear matter

$$\sigma_{\varphi N}^{med} = 35_{-11}^{+17}\, mb$$

(SPRING - 8)

$$23 < \sigma_{\varphi N}^{med} < 63 mb$$

(Cabrera,Muehlich,Sibirtsev)

$$\sigma_{\varphi N}^{free} \approx 10 mb$$

Antiprotons in nuclear matter

ITEP experiment (V. Sheinkman et al.)

$pA \longrightarrow \bar{p}X;$

E_p = 5.5 GeV, **7.2 GeV, 9.2 Gev**

Be, Al, **Cu, Ta**

0.7 GeV/c < $P_{\bar{p}}$ < 2.5 GeV/c

$\Theta = 10^o$ (lab)

Data analysis in frame of folding model

(Yu. Kiselev, E. Paryev, nucl-th/0601036)

Antiprotons in nuclear matter

Distortion factor in form:

$$P = \exp(-\int_z^\infty d\vec{l}\,\sigma_{hN}^{med}(p_h)\rho(r'))$$

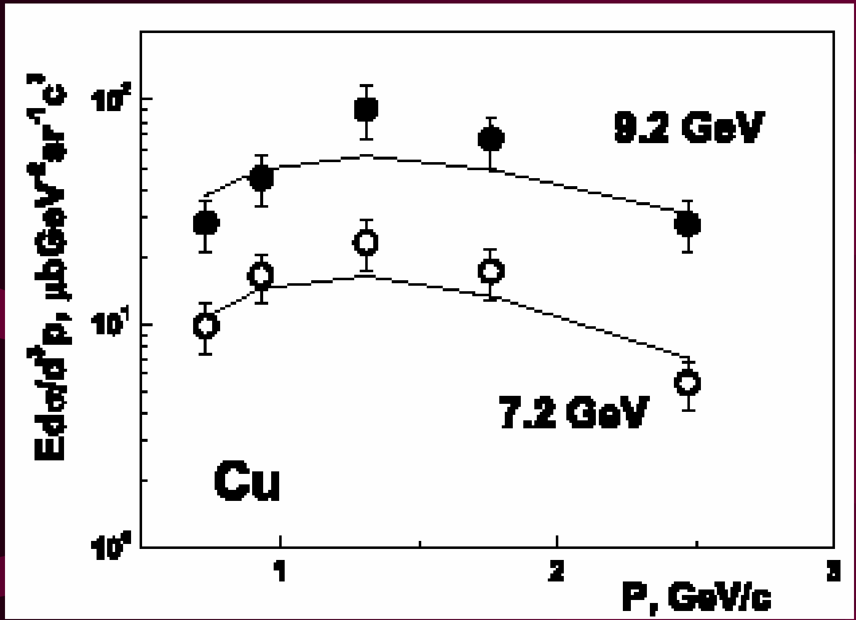
Calculation 1: $\sigma_{\bar{p}N}^{med} = \sigma_{\bar{p}N}^{free}(p_{\bar{p}})$

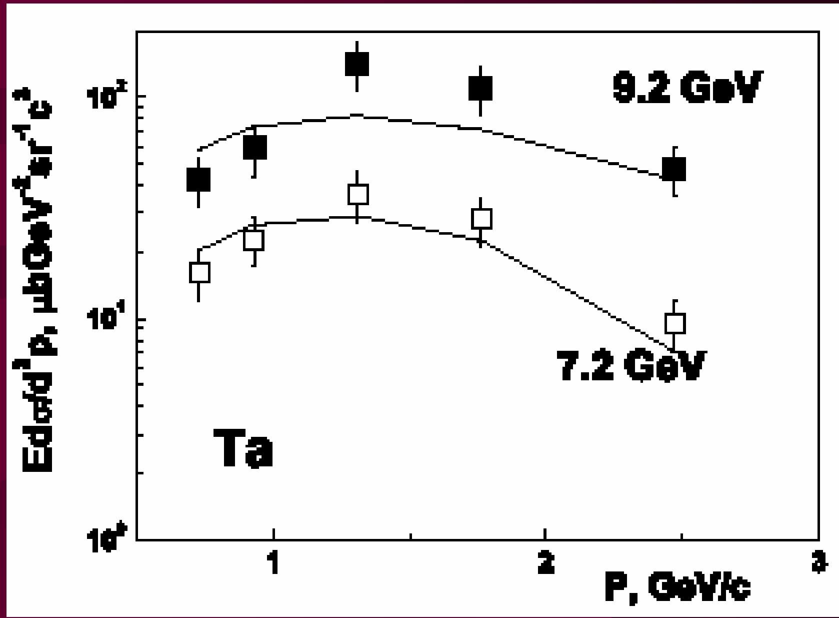
underestimates data by a factor of ~ 2.5

Calculation 2: $\sigma_{\bar{p}N}^{med}$ is a free parameter

$$\sigma_{\bar{p}N}^{med} = 35 \pm 12 mb$$

Antiprotons in nuclear matter





Invariant cross sections for antiproton production in pCu and pTa interactions at initial proton energies of 7.2 and 9.2 GeV as a function of $\overline{p}$ momentum.

Free $\overline{p}$ cross sections:

$\sigma_{\bar{p}N}^{tot} = 140mb$	$\sigma_{\bar{p}N}^{in} = 80mb$	$p_{\bar{p}} = 0.7GeV/c$
$\sigma_{\bar{p}N}^{tot} = 80mb$	$\sigma_{\bar{p}N}^{in} = 50mb$	$p_{\bar{p}} = 2.5GeV/c$

Discussion

Hadron absorption in nuclei looks intriguing

Enhanced φ distortion
Suppressed $\bar{p}$ distortion

$$\sigma_{\varphi N}^{med} \approx \sigma_{\bar{p}N}^{med} \approx 35mb$$

? Unified hadron absorption in nuclear matter ?

Conclusion

More precise experimental data are required to reach better understanding of the hadron distortion in nuclear matter.

ANKE has a good chance to contribute in solving the problem of anomalous φ-meson absorption.