Mass modification of phi meson measured in 12-GeV p+A reaction at KEK-PS E325

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• Physics motivation
• E325 Setup
• Data analysis
• Summary
Quark Mass

**chiral symmetry restoration**

**bare mass**

\[ m_u \approx m_d \approx 5\text{MeV/c}^2 \]
\[ m_s \approx 150\text{MeV/c}^2 \]

**effective mass in QCD vacuum**

\[ m_u \approx m_d \approx 300\text{MeV/c}^2 \]
\[ m_s \approx 500\text{MeV/c}^2 \]

**chiral symmetry braking**

How can we detect such a quark mass change?

**Partial chiral symmetry restoration under normal nuclear density**

Vector Meson
**Vector Meson**

**φ meson**
- Mass decreases \( \sim 20-40 \text{MeV}/c^2 \)
- Narrow decay width \( \Gamma = 4.3 \text{MeV}/c^2 \)
  \( \Rightarrow \) sensitive to the mass spectrum change
- Small decay Q value \( Q_{\text{K}+\text{K}^-} = 32 \text{MeV}/c^2 \)
  \( \Rightarrow \) the branching ratio is sensitive to \( \phi \) (or \( K \)) meson modification

*For example*
- \( \phi \) mass decreases
  \( \Rightarrow \Gamma_{\text{K}+\text{K}^-} \) becomes small
- \( K \) mass decreases
  \( \Rightarrow \Gamma_{\text{K}+\text{K}^-} \) becomes large

**Important points for \( \phi \) meson modification**
1. Invariant mass spectrum, with good mass resolution
2. Nuclear size dependence of the branching ratio between the \( e^+e^- \) and \( \text{K}^+\text{K}^- \) channels

**Predictions of vector meson modification in medium**

**For example**
- \( \phi \) mass decreases
  \( \Rightarrow \Gamma_{\text{K}+\text{K}^-} \) becomes small
- \( K \) mass decreases
  \( \Rightarrow \Gamma_{\text{K}+\text{K}^-} \) becomes large

**Important points for \( \phi \) meson modification**
- Invariant mass spectrum, with good mass resolution
- Nuclear size dependence of the branching ratio between the \( e^+e^- \) and \( \text{K}^+\text{K}^- \) channels

**References**
KEK-PS E325

**Measurements**
Invariant Mass of $e^+e^-, K^+K^-$ in 12GeV $p+A \rightarrow \rho, \omega, \phi + X$ reactions

slowly moving vector mesons ($p_{lab} \sim 2\text{GeV/c}$)

large probability to decay inside a nucleus

**Beam**
Primary proton beam
($\sim 10^9$/spill/1.8s)

**Target**
Very thin targets
e.g. 0.4% radiation length &
0.2% interaction length for C-target

A combination of very thin targets with high intensity beam is very important to reduce the background from $\gamma$ conversion.
Setup

Forward LG Calorimeter

Rear LG Calorimeter

Side LG Calorimeter

Barrel Drift Chamber

Cylindrical DC

Vertex DC

12GeV proton beam

Start Timing Counter

Hodoscope

Aerogel Cherenkov

Forward TOF

Mass Spectra

\[ \text{counts}/(6.7\text{MeV}/c^2) \]

\[ \text{counts}/(4\text{MeV}/c^2) \]

\[ \phi \quad \text{C} \quad \phi \quad \text{Cu} \]

\[ K^+ K^- \quad \text{threshold} \]
Kinematical Distributions for observed $\phi$

The detector acceptance is different between $e^+e^-$ and $K^+K^-$

$\rightarrow$ But there is an overlap region

Slowly moving $\phi$ meson should have larger probability
to decay inside a nucleus
Fitting Methods

● **Background**: quadratic curve \((e^+e^-)\) mixed event method \((K^+K^-)\)

● **Shape**: Breit-Wigner distribution smeared by taking the experimental effects into account using Geant4 simulation – physical processes and detector effects

● **Examine the mass shape as a function of** \(\beta\gamma\) → Next
Fit Results for $e^+e^-$ (divided by $\beta\gamma$)

$\beta\gamma < 1.25$ (Slow)  
$1.25 < \beta\gamma < 1.75$  
$1.75 < \beta\gamma$ (Fast)

Data cannot be reproduced (99% C.L.)
A significant enhancement is seen in the Cu data, in $\beta\gamma<1.25$

- the excess is attributed to the $\phi$ mesons which decay inside the nucleus and are modified

I. Fit the spectra again by excluding the excess region, 0.95~1.01GeV/c²
II. Integrate the spectra in the excess region
III. Subtract the background and the normal phi meson shape which are determined by the fit

The model calculation reproduces the tendency of our data
Fit Results for $K^+K^-$ (divided by $\beta\gamma$)

$\beta\gamma < 1.7$ (Slow)  
$1.7 < \beta\gamma < 2.2$  
$2.2 < \beta\gamma$ (Fast)

- Large Nucleus
- Small Nucleus

Counts/4MeV/c$^2$

Mass spectrum changes are NOT statistically significant

- the statistics in the $K^+K^-$ mode is much less than those in the $e^+e^-$ mode
- $K^+K^-$ data is extremely limited in $\beta\gamma < 1.25$
\[ \sigma(A) = \sigma(A = 1) \times A^\alpha \]

**example of \( \alpha \) change**

- \( \Gamma_{K^+K^-}/\Gamma_{e^+e^-} \) increases in a nucleus
  \[ \Rightarrow N_{\phi \to K^+K^-}/N_{\phi \to e^+e^-} \] becomes large
- The larger modification is expected in the larger nucleus

- \( \alpha_{\phi \to K^+K^-} \) becomes larger than \( \alpha_{\phi \to e^+e^-} \)
- The difference of \( \alpha \) is expected to be enhanced in slowly moving \( \phi \) mesons

\( \alpha_{\phi \to K^+K^-} \) looks larger than \( \alpha_{\phi \to e^+e^-} \) in lower \( \beta \gamma \) region

- \( e^+e^- \)
- \( K^+K^+ \)
Summary

• KEK PS-E325 measures $e^+e^-$ and $K^+K^-$ invariant mass distributions in 12GeV p+A reactions.

• **Significant enhancement** is seen on the $e^+e^-$ invariant mass distributions at the low-mass side of the $\phi$ meson peak in the Cu data, in $\beta\gamma < 1.25$ region. Model calculations reproduce the tendency of our data when the mass modification of $\phi$ is taken into account.

• Mass spectrum changes are **NOT** statistically significant in $K^+K^-$ invariant mass distributions. Our statistics in the $K^+K^-$ decay mode are quite low in the $\beta\gamma$ region in which we see the enhancement in the $e^+e^-$ mode.

• $\alpha_{\phi \rightarrow K+K^-}$ looks **larger** than $\alpha_{\phi \rightarrow e^+e^-}$ in lower $\beta\gamma$ region. This is very interesting observation, because it can be related to the $\phi$ and Kaon modification in nuclear matter.