Search for $\phi$ meson-nuclear bound state

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Introduction
φ meson

- φ meson:
  - Vector meson, \( J^{PC} = 1^- \)
  - the lightest bound state of hidden strangeness (\( \bar{s}s \))
  - narrow width = 4.43 MeV/c\(^2\), Long life time = 45 fm/c

- Interaction between φ-nucleon
  - \( \phi \)-N interaction could be attractive.
    \( \rightarrow \) QCD van der waals interaction (multi-gluon exchange)
φ meson in nucleus

Progress of Theoretical Physics, Vol. 98, No. 3, September 1997

QCD Sum Rules for ρ, ω, φ Meson-Nucleon Scattering Lengths and the Mass Shifts in Nuclear Medium

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(Received April 14, 1997)

- Expected mass shift of φ ~ 1-2% (@ ρ=ρ₀)
  = 10 MeV to 20 MeV

\[ a_ρ = -0.47 \pm 0.05 \text{ fm}, \]
\[ a_ω = -0.41 \pm 0.05 \text{ fm}, \]
\[ a_φ = -0.15 \pm 0.02 \text{ fm}, \]
Theoretical prediction?

about $f$ meson bound state
Theoretical prediction?

Formation of $\phi$ Mesic Nuclei

Junko Yamagata-Sekihara, 1,* Daniel Cabrera, 2 Manuel J. Vicente Vacas 3 and Satoru Hirenzaki 4

No clear structure.

The $\phi$–NN and $\phi\phi$–NN mesic nuclear systems

The $\phi$NN bound state are expected : BE~20-30 MeV
$\phi$ meson in nucleus
- experiment -
Evidence for In-Medium Modification of the $\phi$ Meson at Normal Nuclear Density

R. Muto,1,2,3 I. Chiba,2,4 H. En'yo,1 Y. Fukao,5 H. Funahashi,1 H. Hamagaki,6 M. Iseri,7 M. Ishino,3,4 H. Kajita,2,8 M. Kitaguchi,7 S. Mihara,5,9 K. Miwa,7 T. Miyashita,5 T. Murakami,3 T. Nakura,3 M. Naruki,1 K. Ozawa,4,8 F. Sato,11 O. Sasaki,2 M. Sekimoto,2 T. Tabaru,1 K. H. Tanaka,5 M. Togawa,3 S. Yamada,2 S. Yokkaichi,1 and Y. Yoshimura1

(KEK-PS E325 Collaboration)

PRL 98, 042501 (2007)

Existence of attractive interaction between $\phi$-N

3.4% mass shift x 3.6 width broadening
About Decay Width
**φ meson in normal nuclear media**

- Transparency ratio, $T_A = \sigma_{\gamma_A-\phi X}/A(\sigma_{\gamma p-\phi X})$,

- **Data**: PLB 608(2005)215
  $\gamma A\rightarrow\phi X$: Extracted $\sigma_{\phi N} = 30$ mb

- **Analysis**: NPA 765(2006)188
  $\sigma_{\phi N}$ expected (Theo.) $\sim 10$ mb

- discrepancy between $\sigma_{\phi N}$ measured and expected is explained by width broadening of $\phi$ in nuclear media by factor 16! ($\Gamma_{\text{in nucleus}} \sim 70$ MeV)

- $\sigma_{\phi N} \sim 10$ mb: $\lambda_{\text{interaction}} = 7.0$ fm
- $\sigma_{\phi N} \sim 20$ mb: $\lambda_{\text{interaction}} = 3.5$ fm
Why absorption of $\phi$ takes place on deuteron? Is this only a case with gamma induced experiment? 

$\phi$ meson with deuteron

\[ \frac{[d\sigma/dt]}{[2 \times d\sigma_p/dt]} = 0.73 \pm 0.058 \]

Experiment: $\gamma d \rightarrow \phi X$

Extracted $\phi N$ cross section

$\sigma_{\phi N} = 20 \text{ mb}$

Again $\sigma_{\phi N}$ Expected,

$\sigma_{\phi N} = 11 \text{ mb (upper limit)}$

How to explain this discrepancy?
Again width broadening of $\phi$ meson in nuclear matter even on deuteron?
One more

- Momentum dependence of transparency ratio by COSY-ANKE

**Phys. Rev. C 85, 035206 (2012) [8 pages]**

**Momentum dependence of the \( \phi \)-meson nucleon**

**Abstract**

Width increasing? as a function of momentum less absorption with low momentum \( \phi \) meson?
At High Temperature
*$\phi$ meson in hot nuclear media*

- $\phi$ meson production in 158 GeV/c In-In collisions at CERN/SPS (NA60)
- Mass shift and width broadening are not identified in hot nuclear matter (within detector resolution)

![Graph showing $\phi$ meson production and mass pole position with width](image)
New experiment needed to answer the question about $\phi$ meson in nucleus

Two experiments are proposed at J-PARC

1) Study on meson mass modification in nuclei using primary proton beam at J-PARC
   → detail study of $\phi \rightarrow e^+e^-$ in nucleus (J-PARC E16 experiment)

2) Search for $\phi$ meson bound state
Key point to produce $\phi$ meson bound state

- We want to embedding $\phi$ meson in nucleus

- What we need?
  - Low momentum $\phi$ meson beam → which is not available
  - Then, can we producing $\phi$ meson in nucleus?
• Double $\phi$ meson production in $\bar{p}p$ reaction

$\phi\phi$ production dominated around production threshold
Background processes

List of background

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma_{Total}$ (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>signal</td>
<td>$23 \times 10^{-3}$</td>
</tr>
<tr>
<td>$\pi^+\pi^0\pi^-$</td>
<td>33.</td>
</tr>
<tr>
<td>$2\pi^+2\pi^-$</td>
<td>47.</td>
</tr>
<tr>
<td>$\pi^+2\pi^0\pi^-$</td>
<td>14.</td>
</tr>
<tr>
<td>$2\pi^+\pi^02\pi^-$</td>
<td>224.</td>
</tr>
<tr>
<td>$2\pi^+2\pi^02\pi^-$</td>
<td>125.</td>
</tr>
<tr>
<td>$3\pi^+3\pi^-$</td>
<td>18.</td>
</tr>
<tr>
<td>$2\pi^+3\pi^02\pi^-$</td>
<td>86.</td>
</tr>
<tr>
<td>$2\pi^+4\pi^02\pi^-$</td>
<td>22.</td>
</tr>
</tbody>
</table>

Event selection like 3 strangeness, i.e. 3 Kaons in a events reduce background significantly.
Concept for the experiment

\[ \bar{p} + \frac{A+1}{Z+1} X' \rightarrow \{ \phi \frac{A}{Z} X \} + \phi \]

- Missing mass by forward going $\phi$ meson
- Strangeness tagged by decay product

$\Delta m = 0$

$\Delta m = 30$ MeV
Anti-proton beam at J-PARC
J-PARC secondary beam line

- Low momentum $p$ beam available

- One production target for secondary beam ($\pi^\pm, K^\pm, p, \bar{p}$)
- Three secondary beamlines (max. momentum)
  - K1.8BR: up to 1.1 GeV/c
  - K1.8: up to 2.0 GeV/c
  - K1.1: up to 1.1 GeV/c

$\sim 1 \text{ M } \bar{p} / \text{ pulse (3.5s)}$
@ 1 GeV/c
will be able to use for experiments
Study of in medium mass modification for the $\phi$ meson using $\phi$ meson bound states in nucleus

J-PARC E29 experiment


29 members from 10 institute
What we need?

\[ \overline{p} + \frac{A+1}{Z+1} X' \rightarrow \{ \phi \frac{A}{Z} X \} + \phi \]

High resolution forward Kaon spectrometer

\( \phi \) absorbed by nucleon

Large angle charged particle Spectrometer for decay product

\( \phi N \rightarrow K \Lambda \), for example.
Conceptual design of the detector

- Large solid angle charged particle spectrometer (with large gap dipole magnet)

Using antiproton beam with 1.0 – 1.1 GeV/c

Large acceptance for forward going $\phi$ meson (for missing mass analysis)

Large solid angle for the decay particles, $K^+ / \Lambda$, from $\phi$ mesic nucleus
Typical event display

- \( p + Cu \rightarrow \phi + _f^5\text{Ni} \) (\( B_f = 30 \text{ MeV} \))
- \( \phi + p \rightarrow K^+ + \Lambda \)  
  (proton & \( f \) at rest)
- All decay processes are isotropic.

Detector simulation using GEANT4 is in progress
Expected Signal + background

- Expected missing mass distribution with background (On Carbon target):
  - 270 kW, one month

- Assumption for the signal
  - $\Delta m_\phi = 35$ MeV
  - $\Gamma_\phi = 15$ MeV
Expected Signal + background

- Expected missing mass distribution with background (On Carbon target):
  - Assumption for the signal
    \( \Delta m_\phi = 35 \text{ MeV} \)
    \( \Gamma_\phi = 15 \text{ MeV} \)
  - 270 kW, one month
However, problems? on double $\phi$ meson production
Double $\phi$ meson production

- Strong OZI violated process
  - It is very hard to understand the reason of large cross section at threshold

\[
\bar{p} p \rightarrow \phi \phi \text{(JETSET)}
\]
Double $\phi$ meson production

- Recently, $\omega\phi$ bound system has been observed? at BESII (PRL96(2006)162002)

- Moreover $\gamma\gamma\to\phi\phi$ has been measured at Belle with high statistics (PRL108(2012)232001).

Why not in $\phi\phi$???

$\phi\phi$ production itself is still interesting very much!
1\textsuperscript{st} phase for E29

We are now planning to perform 1\textsuperscript{st} phase experiment using spectrometer at K1.8BR beamline

- Maximum momentum for anti-proton at J-PARC/K1.8BR $\rightarrow$ 1.1 GeV/c
- Unfortunately, cross section of double $\phi$ meson production only available from $\bar{p}$ monemtum $= 1.2$ GeV/c and higher
- Thus, we are planned to perform the experiment to confirm the cross section of $\bar{p}p \rightarrow \phi\phi$ with $p$ momentum lower than 1.2 GeV/c (no data available) on hydrogen target
- Also planned to take data with deuteron (or light nuclei)
Idea for phase-1 experiment

- Using E15 spectrometer
- Large acceptance charged particle spectrometer surrounding target (CDS).
- Detecting $K^+K^-$ pairs from $\phi$ decay in CDS
- Calculate invariant mass of $K^+K^-$ and missing mass, then we can identify double $\phi$ production

Good enough to investigate elementary process!
Idea for phase-1 experiment

Signal

Angular acceptance
Plane for next years

- We will ask to J-PARC PAC (probably next January) for approval of E29 1\textsuperscript{st} phase experiment
  - Perform the experiment at K1.8BR
  - Using Detector ready exist
    → Problem might be a beam time availability

- Once we finish to taking data and confirm the cross section of double $\phi$ production, we will go forward to perform full experiment to search for $\phi$ meson bound state
The project to searching for $\phi$ meson bound state has been proposed to J-PARC and now we got stage-1 approval (E29).

The most promising elementary process for the $\phi$ mesic nucleus production will be $\bar{p}p\rightarrow\phi\phi$ channel.

Preparation for the E29 phase-1 is in progress.