In-Medium Modifications of $\omega$ Meson

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Model predictions for in-medium spectral functions of the $\omega$ meson

1.) lowering of in-medium mass
2.) broadening of resonance

- theoretical prediction for $\omega$ meson at rest in nuclear medium; experiment has to be sensitive to low momentum $\omega$ mesons
experimental approach:

hadron decay in the medium: $H \to X_1 X_2$

- reconstruction of invariant mass from 4-momenta of decay products:

$$\mu_H(\rho, \bar{\rho}) = \sqrt{(p_1 + p_2)^2}$$

- compare $\mu_H(\rho, \bar{\rho} \to 0)$ with $m_H$ listed in PDG

- ensure that decays occur in the medium:
  → select shortlived mesons ($c\tau = \frac{\hbar c}{\Gamma}$; $\rho$: 1.3 fm; $\omega$: 23 fm; $\phi$: 46 fm)
  → cut on low meson momenta

- avoid distortion of 4-momentum vectors by final state interactions
  ⇒ dilepton spectroscopy: $\rho$, $\omega$, $\phi \to e^+e^-$

- experimentally observed mass distribution = convolution of spectral function with branching ratio into channel being studied

$$\frac{d\sigma_{H\to X_1 X_2}}{d\mu} \sim A(\mu) \cdot \frac{\Gamma_{H\to X_1 X_2}}{\Gamma_{\text{tot}}(\mu)}$$

F. Eichstaedt et al.,
Sensitivity to in-medium signal

Strength function parametrized by Breit-Wigner shape

\[
\frac{d\sigma}{d\mu} \sim A(\mu) \cdot \frac{\Gamma_{V\to\text{final state}}}{\Gamma_{\text{tot}}} = \frac{\mu \cdot \Gamma_{\text{tot}}}{(\mu^2 - m_V^2)^2 + \mu^2 \Gamma_{\text{tot}}^2} \cdot \frac{\Gamma_{V\to\text{final state}}}{\Gamma_{\text{tot}}} \sim \frac{1}{\rho^2}
\]

\[\Gamma_{\text{tot}} = \Gamma_{\text{vac}} + \Gamma_{\text{med}}\]

In low density approximation:

\[\Gamma_{\text{med}}(\rho(r)) = \Gamma_{\text{med}}(\rho_0) \cdot \frac{\rho(r)}{\rho_0}\]

for a large in-medium broadening of the meson \[\Gamma_{\text{tot}} \approx \Gamma_{\text{med}} \sim \rho\]
as observed for the \(\omega\) meson: \[\Gamma_{\text{tot}} \approx 16 \cdot \Gamma_0\] (M. Kotulla et al., PRL 100 (2008) 192302)

- contributions from higher densities suppressed by order of \(1/\rho^2\)

- for cases of strong in-medium broadening (\(\omega, \Phi\)) it is in principle difficult to observe in-medium shape changes;

ω-mass in nuclei from photonuclear reactions

CBELSA/TAPS photon detector

\[ \gamma A \rightarrow \omega + X \]
\[ m_\omega = \sqrt{(p_\pi + p_\gamma)^2} \]

**advantage:**
- \( \pi^0 \gamma \) large branching ratio (8.3 \( \times \) 10\(^{-2} \))
- no \( \rho \)-contribution (\( \rho \rightarrow \pi^0 \gamma : 7 \times 10^{-4} \))

**disadvantage:**
- \( \pi^0 \)-rescattering reduced by removing low-energy pions (T_{\pi}\textgreater150 \text{MeV})

**results:** CBELSA/TAPS collaboration
- D. Trnka et al. PRL 94 (2005)192303
  \[ \frac{\Delta m_\omega}{m_\omega} \approx -14\% \text{ at } \rho = \rho_0 \text{ from lineshape analysis} \]
- M. Kotulla et al. PRL 100 (2008)192302
  \[ \Gamma_\omega(\rho_0) \approx 130 - 150 \text{ MeV for } \langle p_\omega \rangle \approx 1.1 \text{ GeV} / c; \]
  \[ \Gamma_\omega(\rho = \rho_0) \approx 16 \cdot \Gamma_0 \text{ from transparency ratio} \]
Extraction of omega signal

Dominating background from $\pi^0\pi^0$, $\pi^0\eta \rightarrow 4\gamma$ events, missing 1 $\gamma$

background generated from $\pi^0\pi^0$, $\pi^0\eta \rightarrow 4\gamma$ events, omitting 1 $\gamma$

normalization of background: counts in signal and background spectrum identical in $411\ MeV < M(\pi^0\gamma) < 906\ MeV$ apart from 2% correction for $\omega$ signal

\[ \gamma + \text{Nb} \rightarrow \omega + p + X \]

D. Trnka et al, PRL 94 (2005) 192303

background well reproduced by 4n + 1ch events, omitting 1 $\gamma$

not inconsistent with previous Trnka result!!
Comparison to $\omega$ line shape for LH$_2$ target

**fit function:**

$$f(x) = A \exp\left(-0.5 \left( \frac{\log q_s}{d} \right)^2 - d^2 \right)$$

$$q_s = 1 + \left( \frac{x-b}{c} \right) \sinh\left( d \sqrt{\log 4} \right)$$

where:
- $A$ – amplitude
- $b$ – peak position
- $c$ – width
- $d$ – tail

- no discrepancy with the previous results
  
  D. Trnka et al. PRL 94(2005) 192203

- no discrepancy with $\omega$ lineshape for LH$_2$

 RESULT INCONCLUSIVE!

sensitivity?
Sensitivity of the experiment to an in-medium mass shift

**Gi-BUU simulations:** K. Gallmeister et al. Prog. Part. Nucl. Phys. 61 (2008) 283

3 scenarios:
1.) no in-medium modification
2.) broadening only
3.) broadening and mass shift ($\alpha = -0.16$)

For $E_\gamma = 1500 – 2200$ MeV, scenarios not distinguishable; effect only observable for extremely hard cut on $\omega$ momentum $\rightarrow$ loss in intensity.

- $\omega$ signal consistent with "broadening + mass shift" and other scenarios; $\Rightarrow$ insensitive!!
Sensitivity of the experiment to an in-medium mass shift

**Gi-BUU simulations:** K. Gallmeister et al. Prog. Part. Nucl. Phys. 61 (2008) 283

3 scenarios:
1.) no in-medium modification
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3.) broadening and mass shift ($\alpha = -0.16$)

$$m(\rho) = m_0 \cdot \left( 1 + \alpha \frac{\rho}{\rho_0} \right)$$

$E_\gamma = 900 - 1200$ MeV; $E_{\gamma N}^{\text{thr}} = 1108$ MeV

- for $E_\gamma = 900 - 1200$ MeV possible mass shift observable near threshold even without cut on $\omega$ momentum

- experimental data closer to line shape predicted for “broadening only”

data taken at MAMI C with 2 times higher statistics in $E_\gamma = 800-1400$ MeV; analysis ongoing
summary

• **in-medium signal strongly suppressed** for strong in-medium broadening of meson: $\omega, \phi$

• **re-analysis of D. Trnka data**: PRL 94 (2005) 192303
  - background determination in shape and absolute magnitude from the data
  - re-analysis yields $\omega$ signal which is **not inconsistent** with the result by D. Trnka et al., where mass shift was claimed
  - $\omega$ signal consistent with line shape for production on free proton (applied cut $T_\pi > 150$ MeV)
  - $\omega$ signal consistent with a mass shift predicted in Gi-BUU calculations
  $\Rightarrow$ experiment **inconclusive** for incident photon energies 900-2200 MeV

• **higher sensitivity** to in-medium properties of $\omega$ meson for incident energies near production threshold
  - the preliminary results from MAMI C data are consistent with the conclusions from the re-analysis of CBELSA/TAPS data for incident photon energies 900-1400 MeV