Measurements of vector meson decays in nuclear matter at KEK–PS

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- vector meson modification & chiral symmetry
- performed experiment
- observed invariant mass spectra
- discussion
Chiral symmetry restoration in dense matter

- In hot/dense matter, chiral symmetry is expected to restore
  - hadron modification is expected in such matter
- quark–antiquark condensate (order parameter) is predicted
  ~2/3 even at the normal nuclear density
  - Achievable at KEK–PS, not RHIC

- Various theoretical predictions of vector meson (mass/width)
  modification in dense medium....
  - Brown, Rho (’91), Hatsuda, Lee (’92), Klingle, Keiser, Weise (’97), Muroya, Nakamura, Nonaka (’03)....
Hatsuda and Lee, 92, 95
mass decreasing
~16% for $\rho/\omega$
~2–4% for $\phi$
at the normal nuclear density

Muroya, Nakamura, Nonaka, 03

Klinge, Keiser, Weise, 97
Invariant mass spectra in $e^+e^-$ channel

- smaller FSI in $e^+e^-$ decay channel
- double peak or tail–like structure
  - second peak is made by inside–nucleus decay (modified meson)
- comparison of $\phi$ and $\rho$
  - $\phi$ (1020): narrow width
    - smaller decay prob. inside nuclei
    - smaller production CS
  - $\rho$ (770) & $\omega$ (783)
    - larger production CS
    - larger decay prob. inside nuclei
    - cannot distinguish $\rho$ & $\omega$ in $e^+e^-$

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Experiment KEK–PS E325

- 12GeV p+A → ρ/ω/φ +X, (ρ/ω/φ → e^+e^−, φ→K^+K^-)

- Experimental key issues:
  - Very thin target to suppress the conversion electron background (typ. 0.1% interaction/0.2% radiation length of C)
  - To compensate the thin target, High intensity proton beam to collect high statistics (typ. 10^9 ppp → 10^6Hz interaction)
  - Detect slowly moving mesons, which have larger probability decaying inside nuclei (1<βγ<3)

Collaboration

(Kyoto Univ., RIKEN, KEK, CNS–U.Tokyo, ICEPP–U.Tokyo, Tohoku–Univ.)
• KEK–PS EP1–B primary beam line
• 1996 const. start
• ’97 data taking start
• ’98 ee data is published
  – PRL86(01)5019
• 99,00,01,02,...
• ’02 completed
- **Spectrometer Magnet**
  - 0.71T at the center
  - 0.81Tm in integral

- **Targets**
  - at the center of the Magnet
  - C & Cu are used typically
  - very thin: ~0.1% interaction length

- **Primary proton beam**
  - 12.9 GeV/c
  - ~1x10⁹ in 2sec duration, 4sec cycle
Electron ID counters
  Gas Cherenkov & Lead Glass EMC
  total $3 \times 10^{-4}$ $\pi$ rejection
  with 78% e efficiency
  in two-stage operation

Tracker
  Three Drift Chambers
• Typical $e^+e^-$ Event
  - **blue**: electron
  - **red**: other
  - invariant mass of electron pair is calculated
Observed $e^+e^-$ invariant mass spectra

- from 2002 run data (~70% of total data)
- C & Cu target
- clear resonance peaks
- $m<0.2$ GeV is suppressed by detector acceptance
- acceptance uncorrected
Fitting with known sources

- Hadronic sources of $e^+e^-$:
  - $\rho/\omega/\phi \rightarrow e^+e^-$, $\omega \rightarrow \pi^0e^+e^-$, $\eta \rightarrow \gamma e^+e^-$
  - simple Breit–Wigner shape (no modification is assumed)
  - Geant4 detector simulation (energy loss of $e^+/e^-$ in detector, acceptance, etc.)

- Combinatorial background: event mixing method

- ... relative abundance of these components are determined by fit

- **excess** at the low–mass side of $\omega$ (0.6–0.75 GeV)
- $\rho$–meson component seems to be **vanished**!
Fitting results (BKG subtracted)

\[ \frac{\rho}{\omega} = 0.0 + 0.01 \text{(stat.)} + 0.2 \text{(sys.)}, \quad 0.0 + 0.05 \text{(stat.)} + 0.5 \text{(sys.)} \]

- However, \( \frac{\rho}{\omega} \sim 1 \) in former experiment (p+p, 1974)
  .......... suggests the excess is from modified \( \rho \) mesons?

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Discussion: Toy model including modification

- Assumptions to include the nuclear size effect in the fitting shape
  - nuclear density distribution: *Woods–Saxon* form
  - meson production point: incident *surface* of nuclei
  - fly through the nucleus, decay with modified mass if the decay point is inside nuclei
  - 
  - modification as: \( \frac{m^*}{m_0} = 1 - 0.16 \frac{\rho^*}{\rho_0} \) 
    (Hatsuda & Lee, ’92,’95)
    - (width modification & momentum dependence of modification are not taken into account)

- \( \frac{\rho}{\omega} \) ratio is fixed to unity as measured in former exp.
Fitting results by the toy model

- the tendency of the data are reproduced qualitatively by the model
\textbf{e}^{+}\textbf{e}^{-} \text{ spectra of } \phi \text{ meson }

\begin{itemize}
\item all statistics for \( \phi \) meson... \( \sim 1000 \phi \) s for each target.
\end{itemize}

\textbf{work in progress}
Summary

- KEK–PS E325 measured the $e^+e^-(&K^+K^-)$ decay of slowly moving vector mesons in nuclei produced by 12GeV proton beam, to explore the chiral symmetry restoration at the normal nuclear density.

- Observed $e^+e^-$ invariant mass spectra have excesses below the $\omega$ meson peak, which cannot be explained by known hadronic sources in normal (unmodified) shape. These suggest modification of (at least) $\rho$ meson.

- Simple model calculation including predicted modification reproduces the observed spectra qualitatively.

- Analysis on $\phi$ meson is also on going...