Modification of $\rho/\omega/\phi$ mass spectra measured at the KEK 12GeV PS

Satoshi Yokkaichi, RIKEN for the KEK-PS E325 collaboration

- **Introduction**
  - chiral symmetry restoration
  - experiments
- **KEK-PS E325 Results**
  - 1) $\rho/\omega/\phi \rightarrow e^+e^-$ spectra
  - 2) $\phi \rightarrow K^+K^-$ spectra
spontaneous chiral symmetry breaking in QCD

- Origin of hadron (nucleon) mass (and light quark mass in hadrons)
  - spontaneous breaking of the chiral symmetry
- confinement-deconfinement phase transition and chiral phase transition occur at the same temperature in lattice calc. (fig:PRD58(98)034504)
Chiral symmetry restoration in a medium

- quark-antiquark condensate (order parameter of the chiral symmetry):

- In hot/dense matter, chiral symmetry is expected to restore
  - hadron modification is expected

- Experiments
  - Vector mesons (ρ / ω / φ), σ meson, S11(1535), etc.
  - deeply bound pionic atom
Deeply bound pionic atom

- optical potential $b_1$
  - → pion decay const. (TW)
  - → chiral condensate (GOR)
  - $\langle \bar{q}q \rangle_{\rho_0} / \langle \bar{q}q \rangle_0 \sim 0.67$

K. Suzuki et al,
PRL92(04)072302
**σ**_**meson**

- Hatsuda, Kunihiro, Shimizu
  (PRL63(99)2840)
  - prediction: in-medium σ meson spectrum

- CHAOS experiment
  (NPA763(05)80)
  - threshold enhancement in \(π^+π^-\) channel
## Vector meson measurements

- **HELIOS3** (ee, μμ) 450GeV p+Be / 200GeV A+A
- **DLS** (ee) 1 GeV A+A
- **CERES** (ee) 450GeV p+Be/Au / 40-200GeV A+A
- **E325** (ee,KK) 12GeV p+C/Cu
- **NA60** (μμ) 400GeV p+A/158GeV In+In
- **PHENIX** (ee,KK) p+p/Au+Au
- **HADES** (ee) 4.5GeV p+A/ 1-2GeV A+A
- **CLAS-G7** (ee) 1~2 GeV γ+A
- **J-PARC** (ee) 30/50GeV p+A/ ~20GeV A+A
- **CBM/FAIR** (ee) 20~30GeV A+A
- **TAGX** (ππ) ~1 GeV γ+A
- **STAR** (ππ,KK) p+p/Au+Au
- **LEPS** (KK) 1.5~2.4 GeV γ+A
- **CBELSA/TAPS** (π⁰γ) 0.64-2.53 GeV γ + p/Nb

*published/ 'modified' running/in analysis future plan*
Vector meson measurements in HIC

- CERES : $e^+e^-$ (EPJC 41('05)475)
  - anomaly at lower region of $\rho/\omega$
  - in A+A, not in p+A
  - relative abundance is determined by their statistical model

- NA60 : (PRL96(06)162302)
  - $\rho \rightarrow \mu^+\mu^-$:
  - width broadening
  - 'BR scaling is ruled out'

In-In SemiCentral

all $p_T$

$\frac{dN_{\rho}}{dp_T}$, $\eta=3-133$

$dN/dM$ per 20 MeV

excess data

RW (norm.)

BR (norm.)

Vac,$\rho$ (norm.)

cockt,$\rho$ (dashed)

DØ (dashed)
Predictions of vector meson modification

- quark-antiquark condensate (order parameter): \( \sim 2/3 \) even at the normal nuclear density, \( T=0 \)
  - could approach by \( p+A \) reaction

- Many theoretical predictions of vector meson (mass/width) modification in dense medium, related (or not related) with CS
  - Brown & Rho ('91): \( m^*(\rho)/m_0 \sim f^*_\pi/f_\pi \sim 0.8 \) at \( \rho=\rho_0 \)
  - Hatsuda & Lee ('92), Klingle, Kaiser & Weise ('97), Muroya, Nakamura & Nonaka ('03), etc.
Hatsuda and Lee, PRC46(92)R34, PRC52(95)3364
linear dependence on density
\[ m^* / m_0 = 1 - k \rho / \rho_0 \]
mass decreasing
- \(16(\pm 6\%)\) for \(\rho / \omega\)
- \(0.15(\pm 0.05)\)\(\times y\)
  \(= 2\sim 4\%\) for \(\phi\)
    (for \(y = 0.22\))
at the normal nuclear density

Klingl, Kaiser, Weise, NPA624(97)527

Muroya, Nakamura, Nonaka, PLB 551 (03) 305
non-trivial form of the dispersion relation (mass VS momentum)

- S.H.Lee (PRC57(98)927) \( m^*/m_0 = 1 - k \rho/\rho_0 \)
  - \( \rho/\omega \) : \( k=0.16\pm0.06+(0.023\pm0.007)(p/0.5)^2 \)
  - \( \phi \) : \( k=0.15(\pm0.05)y + (0.0005\pm0.0002)(p/0.5)^2 \)
  - for \( p<1\)GeV/c

- Kondratyuk et al. (PRC58(98)1078) : \( \rho \) meson
- Post & Mosel(NPA699(02)169) : \( \rho \) meson
Expected Invariant mass spectra in $e^+e^-$

- smaller FSI in $e^+e^-$ decay channel
- double peak (or tail-like) structure:
  - second peak is made by inside-nucleus decay (modified meson) : amount depend on the nuclear size and meson velocity
  - could be enhanced for slower mesons & larger nuclei

longer-life meson($\omega$ & $\phi$) cases: Schematic picture

outside decay (natural) + inside decay (modified) = expected to be observed
Expected Invariant mass spectra in $e^+e^-$

- smaller FSI in $e^+e^-$ decay channel
- double peak (or tail-like) structure:
  - second peak is made by inside-nucleus decay (modified meson) : amount depend on the nuclear size and meson velocity
  - could be enhanced for slower mesons & larger nuclei

shorter-life meson($\rho$) cases:

<table>
<thead>
<tr>
<th>outside decay</th>
<th>inside decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>(natural)</td>
<td>(modified)</td>
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</tbody>
</table>

Schematic picture expected to be observed
(Expected $e^+e^-$ spectra)

- $\rho$ (770) & $\omega$ (783):
  - larger production cross section
  - larger decay prob. inside nuclei
  - $\rho : \Gamma = 150\text{MeV} \sim 1.3\text{fm}$
  - $\omega : \Gamma = 8.4\text{MeV} \sim 24\text{fm}$
  - cannot distinguish $\rho$ & $\omega$ in $e^+e^-$

1) decay inside nuclei  2) decay outside nuclei

(toy model calc.)
(Expected $e^+e^-$ spectra)

- $\rho$ (770) & $\omega$ (783):
  - larger production cross section
  - larger decay prob. inside nuclei
    - $\rho$: $\Gamma = 150$ MeV ~ 1.3 fm
    - $\omega$: $\Gamma = 8.4$ MeV ~ 24 fm
  - cannot distinguish $\rho$ & $\omega$ in $e^+e^-$

- $\phi$ (1020): narrow width
  - smaller decay prob. inside nuclei
    - $\phi$: $\Gamma = 4.3$ MeV ~ 46 fm
  - smaller production cross section

- $L = \beta\gamma c\tau = p/m * h/2\pi c/\Gamma$
CBELSA/TAPS (PRL94(05)192303)

- $\omega \rightarrow \pi^0\gamma\, (\rightarrow \gamma\gamma\gamma)$
- anomaly in $\gamma + \text{Nb}$, not in $\gamma + \text{p}$
  - shift param. $k \approx 0.13$

![Graph 1](image1.png)
![Graph 2](image2.png)
CLAS-G7 (preliminary, QM2006 etc.)

- $\rho \rightarrow e^+e^-$: no modification ($k=0.02\pm0.02$) w/ Giessen BUU
**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)
  - Large acceptance spectrometer to detect slowly moving mesons, which have larger probability decaying inside nuclei (1<βγ<3)

**Collaboration**

E325 spectrometer located at KEK-PS EP1-B primary beam line
(Cont'd)

- History of E325
  - 1993 proposed
  - 1996 const. start
  - '97 data taking start
  - '98 first ee data
    - PRL86(01)5019
  - 99,00,01,02....
    - x100 statistics
      - PRL96(06)092301
      - PRL98(07)042501
      - PRC74(06)025201
      - nucl-ex/0606029(to be published in PRL)
  - '02 completed
    - NIM A516(04)390

E325 spectrometer
located at KEK-PS EP1-B primary beam line
Experimental setup

- **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
  - ~1x10^9 in 2sec duration, 4sec cycle
• Typical $e^+e^-$ Event
  - blue: electron
  - red: other
  - invariant mass and momentum of mother particle can be calculated
Experimental setup - targets

<table>
<thead>
<tr>
<th>material</th>
<th>beam intensity (p/spill)</th>
<th>Interaction length(%)</th>
<th>radiation length(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>~1x10^9</td>
<td>0.2%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Cu X 4</td>
<td>~1x10^9</td>
<td>0.05%X4</td>
<td>0.6%X4</td>
</tr>
</tbody>
</table>

targets in 2002

e^+e^- sample in '02

Beam

23mm

C

Cu
Spectrometer performance

\[ K^0_s \rightarrow \pi^+\pi^- \]

Data
MC

\[ \Lambda \rightarrow p\pi^- \]

Data
MC

\[ M = 496.8 \pm 0.2 \text{ (MC 496.9)} \text{ MeV/c}^2 \]
\[ = 3.9 \pm 0.4 \text{ (MC 3.5)} \text{ MeV/c}^2 \]

\[ M = 1115.71 \pm 0.02 \text{ (MC 1115.52)} \text{ MeV/c}^2 \]
\[ = 1.73 \pm 0.04 \text{ (MC 1.63)} \text{ MeV/c}^2 \]

mass resolution for \( \phi \)-meson decays

\[ \phi \rightarrow e^+e^- : 10.7 \text{ MeV/c}^2 \]
\[ \phi \rightarrow K^+K^- : 2.1 \text{ MeV/c}^2 \]
E325 Results (1)

ee invariant mass spectra

M. Naruki et al.,
PRL 96 (2006) 092301
R. Muto et al.,
PRL 98 (2007) 042501
measured kinematic distribution of $\omega/\phi \rightarrow e^+e^-$

- $0 < P_T < 1$, $0.5 < y < 2$ ($y_{CM} = 1.66$)

- $1 < \beta\gamma (=p/m) < 3$ ($0.8 < p < 2.4\text{GeV/c}$ for $\omega$, $1 < p < 3\text{GeV/c}$ for $\phi$)
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

→ fit the spectra with known sources
Fitting with known sources

- Hadronic sources of $e^+e^-$:
  - $\rho/\omega/\phi \rightarrow e^+e^-$, $\omega \rightarrow \pi^0e^+e^-$,
  $\eta \rightarrow \gamma e^+e^-$
  - relativistic Breit-Wigner shape
    (without any modifications, but internal radiative corrections are included)
  - Geant4 detector simulation
    - multiple scattering and energy loss of $e^+/e^-$ in the detector and the target materials
    - chamber resolutions
    - detector acceptance, etc.
- Combinatorial background: event mixing method
- Relative abundance of these components are determined by the fitting
experimental effects on the resonance shape

- target material is negligible for ~0.5% radiation length
- detectors: up to 4.5% rad. length for the tracking region
Fitting results

1) excess at the low-mass side of $\omega$

To reproduce the data by the fitting, we have to exclude the excess region: 0.60~0.76 GeV

2) $\rho$–meson component seems to be vanished!
Fitting results (BKG subtracted)

\[ \frac{\rho}{\omega} < 0.06 + 0.09 \text{(syst.)}, \quad < 0.08 + 0.21 \text{(syst.)} \quad (95\% \text{CL}) \]

However, \( \frac{\rho}{\omega} = 1.0 \pm 0.2 \) in former experiment (p+p, 1974)
...suggests that the origin of excess is modified \( \rho \) mesons.
\( \phi \rightarrow e^+e^- \) invariant mass spectra

- from 2001/02 run data
- C & Cu target
- acceptance uncorrected
- mass resolution : 10.7MeV
- fit with
  - simulated mass shape of \( \phi \)
    - (evaluated as same as \( \rho \) & \( \omega \))
  - polynomial curve background
\( \phi \rightarrow e^+e^- \) invariant mass spectra

- from 2001/02 run data
- C & Cu target
- acceptance uncorrected
- mass resolution: 10.7 MeV
- fit with
  - simulated mass shape of \( \phi \)
    - (evaluated as same as \( \rho \& \omega \))
  - polynomial curve background
- examine the 'excess' is significant or not.
  - see the \( \beta \gamma \) dependence: excess could be enhanced for slowly moving mesons
$e^+e^-$ spectra of $\phi$ meson (divided by $\beta\gamma$)

- $\beta\gamma<1.25$ (Slow)
- $1.25<\beta\gamma<1.75$
- $1.75<\beta\gamma$ (Fast)
$e^+e^-$ spectra of $\phi$ meson (divided by $\beta\gamma$)

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

Only slow/Cu is not reproduced in 99% C.L.
Amount of excess

- To evaluate the amount of excess ($N_{\text{excess}}$), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.
Amount of excess

- To evaluate the amount of excess \( N_{\text{excess}} \), fit again excluding the excess region \((0.95\sim1.01\text{GeV})\) and integrate the excess area.
**Discussion : fit with modification**

- Assumptions to include the nuclear size effect in the fitting shape
  - dropping mass: \( M(\rho)/M(0) = 1 - k_1 (\rho/\rho_0) \)
    (Hatsuda & Lee, \( k = 0.16 \pm 0.06 \))
  - width broadening: \( \Gamma(\rho)/\Gamma(0) = 1 + k_2 (\rho/\rho_0) \)
    (\( \sim \) Oset & Ramos)
    (momentum dependence of modification is not taken into account this time)

<table>
<thead>
<tr>
<th>( m^*/m )</th>
<th>( \rho, \omega )</th>
<th>( \phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Gamma^*/\Gamma )</td>
<td>( 1 - k_1 \rho/\omega \rho/\rho_0 )</td>
<td>( 1 - k_1^\phi \rho/\rho_0 )</td>
</tr>
<tr>
<td>generation point</td>
<td>surface</td>
<td>uniform</td>
</tr>
<tr>
<td>( \alpha (\sigma(A) \propto A^\alpha) )</td>
<td>( 0.710 \pm 0.021 )</td>
<td>( 0.937 \pm 0.049 )</td>
</tr>
<tr>
<td>[PRC74(06)025201]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>momentum dist.</td>
<td>measured</td>
<td></td>
</tr>
<tr>
<td>density distribution</td>
<td>Woods-Saxon, ( R = C:2.3\text{fm/Cu:4.1fm} )</td>
<td></td>
</tr>
</tbody>
</table>
Fitting results by the model (\(\rho/\omega\))

Free param.: - scales of background and hadron components for each C & Cu
- modification parameter \(k\) for \(\rho\) and \(\omega\) is common to C & Cu

From the fit: \(k=0.092 \pm 0.002\) : ~ 9% reduced at normal nuclear density
\(\rho/\omega\) ratio: 0.7\(\pm\) 0.1 (C), 0.9\(\pm\)0.2 (Cu): ... \(\rho\) meson returns.
Remark on the model fitting

- constraint at right side of peak
  - Introducing the width broadening \((x2 \& x3)\) are rejected by this constraint
  - prediction of '\(\rho\) mass increasing' is also not allowed.

- \(\rho\) (\(\omega\)) decay inside nucleus:
  - 46\%(5\%) for C, 61\%(10\%) for Cu
  - used spectrum is the sum of the modified and not-modified components.

- momentum dependence of mass shift is not included. (But typical \(p = 1.5\text{GeV/c}\))
Toy model again for $\phi$ meson

- Toy model like $\rho/\omega$ case, except for
  - uniformly made in nuclei
    - measured $\alpha$ of $\phi$ production $\sim 1$
  - $m^*/m_0 = 1 - k_1 \rho/\rho_0$
    (k_1 =0.04, Hatsuda & Lee, '92,'96)

- To reproduce such amount of excess, linear-dependent width broadening is adopted:
  $\Gamma_{\text{tot}}^*/\Gamma_{\text{tot}}^0 = 1 + k_2 \rho/\rho_0$

- $e^+e^-$ branching ratio is not changed
  - $\Gamma_{e^+e^-}^*/\Gamma_{\text{tot}}^* = \Gamma_{e^+e^-}^0/\Gamma_{\text{tot}}^0$

- $k_1$ & $k_2$ is not free param., but fixed.

- fits were done with many combinations of ($k_1$, $k_2$) and data were well reproduced
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  - fits were done with many combinations of $(k_1, k_2)$ and data were well reproduced
Model fitting: parameter $k_1$ and $k_2$

- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1 \rho/\rho_0$
  - $\Gamma_{\text{tot}}^*/\Gamma_{\text{tot}}^0 = 1 + k_2 \rho/\rho_0$

- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the $\chi^2$ as the sum of 6 spectra

$$(k_1=0.04, k_2=2, \chi^2=316)$$
Model fitting: parameter \( k_1 \) and \( k_2 \)

- To determine the shift parameters...
  - \( m^*/m_0 = 1 - k_1 \rho/\rho_0 \)
  - \( \Gamma_{tot}^*/\Gamma_{tot}^0 = 1 + k_2 \rho/\rho_0 \)

- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the \( \chi^2 \) as the sum of 6 spectra for each \((k_1, k_2)\) combination on the grid and make the \( \chi^2 \) contour

**Best Fit Value:**
\[
\begin{align*}
  k_1 &= 0.034^{+0.006}_{-0.007} \\
  k_2^{tot} &= 2.6^{+1.8}_{-1.2} \\
\end{align*}
\]
(3.6 times width broadening at \( \rho_0 \))
comparison w/ the prediction by HL
E325 Results (2)

KK invariant mass spectra

F. Sakuma et al., nucl-ex/0606029
(to be published in PRL)
**K⁺K⁻ spectra of φ meson**

- **slow(βγ<1.7)**
  - C
  - Cu
  - $\chi^2_{\nu}/\text{dof}=43/39$
  - $\chi^2_{\nu}/\text{dof}=33/39$

- **(1.7<βγ<2.2)**
  - C
  - Cu
  - $\chi^2_{\nu}/\text{dof}=24/39$
  - $\chi^2_{\nu}/\text{dof}=46/39$

- **fast(2.2<βγ)**
  - C
  - Cu
  - $\chi^2_{\nu}/\text{dof}=42/39$
  - $\chi^2_{\nu}/\text{dof}=36/39$

- **mass modification is NOT statistically significant** (very low statistics in βγ <1.25 where modification is observed in φ → e⁺e⁻)
measured kinematic distribution of $\phi \to K^+K^-$ & $\phi \to e^+e^-$

- $0.5 < y < 1.5$
- $1 < \beta \gamma < 3$
- $0.5 < P_T < 1.5$
- overlayed
  - $\phi \to K^+K^-$
  - $\phi \to e^+e^-$
mass modification and $\phi$ branching ratio

- small decay Q value (= 32MeV) for $\phi \rightarrow K^+K^-$
  - branching ratio is sensitive to $\phi$ and $K$ mass modification
    - when $\phi$ mass decrease: $\Gamma_{K^+K^-}$ decrease
    - when $K$ mass decrease: $\Gamma_{K^+K^-}$ increase
- change of the ratio: $\Gamma_{K^+K^-}/\Gamma_{e^+e^-}$ can be studied by measurement of $\alpha$ parameter: the nuclear dependence of production cross section
  - measure both $\phi \rightarrow K^+K^-$ & $\phi \rightarrow e^+e^-$ simultaneously
  
=> NEXT
**nuclear dependence $\alpha$ of the prod. CS of $\phi$ in $K^+K^-$ & $e^+e^-$ channel**

- nuclear dependence $\alpha$:
  
  $\sigma (A) = \sigma_0 \times A^\alpha$

- $\alpha$ and $\Gamma$ : for example
  
  - $\Gamma_{K+K^-}/\Gamma_{e+e^-}$ increases in nuclei,
    $N_{K+K^-}/N_{e+e^-}$ becomes larger
  
  - larger modification expected in larger nuclei
  
  - then, $\alpha_{K+K^-} > \alpha_{e+e^-}$, especially for slowly moving mesons

- ...looks such tendency but consistent within the errors
nuclear dependence $\alpha$ of the prod. CS of $\phi$ in $K^+K^-$ & $e^+e^-$ channel

- nuclear dependence $\alpha$:
  - $\sigma(A) = \sigma_0 \times A^{\alpha}$

- $\alpha$ and $\Gamma$ : for example
  - $\Gamma_{K^+K^-}/\Gamma_{e^+e^-}$ increases in nuclei,
    $N_{K^+K^-}/N_{e^+e^-}$ becomes larger

  - larger modification expected in larger nuclei

  - then, $\alpha_{K^+K^-} > \alpha_{e^+e^-}$, especially for slowly moving mesons

- ...looks such tendency but consistent within the errors : $\alpha_{K^+K^-} - \alpha_{e^+e^-} = 0.14 \pm 0.12$
Limit to the $\phi$ width broadening

- limitation from the $\Delta\alpha$:
  - $k_K$ and $k_e$
- limitation from the KK spectra
  - $k_K < 6.0$ (90%CL)

\[
\Gamma^*_\phi / \Gamma^0_\phi = 1 + k_{\text{tot}} \left( \rho / \rho_0 \right), \\
\Gamma^*_\phi \ k^+K^- / \Gamma^0_\phi \ k^+K^- = 1 + k_K \left( \rho / \rho_0 \right), \\
\Gamma^*_\phi \ e^+e^- / \Gamma^0_\phi \ e^+e^- = 1 + k_e \left( \rho / \rho_0 \right)
\]
Summary

- KEK-PS E325 measured the $e^+e^-$ & $K^+K^-$ decay of slowly moving vector mesons in nuclei produced by 12-GeV 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 of $\rho$ & $\omega$ reproduces the observed spectra.

- $\phi \rightarrow e^+e^-$ also have excess, for the larger target, slowly moving component
  - model calc. including mass shift and width broadening in nuclei also reproduces the data.

- In $\phi \rightarrow K^+K^-$ spectra, no modification is observed. Limit to the width broadening is set.
### Summary Table (V. Metag, QM2006)

<table>
<thead>
<tr>
<th></th>
<th>KEK</th>
<th>Jlab</th>
<th>CBELSA/TAPS</th>
<th>CERES</th>
<th>NA 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega$</td>
<td>–</td>
<td>–</td>
<td>mass shift: -14% $\Gamma_{\omega}(\rho=\rho_0)\approx 100\text{MeV}$</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$\rho$</td>
<td>mass shift: -9% no broadening</td>
<td>no mass shift some broadening</td>
<td>–</td>
<td>broadening favored over density dependent mass shift</td>
<td>no mass shift strong broadening</td>
</tr>
<tr>
<td>$\Phi$</td>
<td>mass shift: -4% $\Gamma_\phi(\rho_0)=47\text{MeV}$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
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# Summary Table (SY)

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<td>ω</td>
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<td>−</td>
<td>−</td>
</tr>
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<td>−</td>
<td>−</td>
<td>no mass shift strong broadening</td>
</tr>
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</table>

\(~16\text{MeV}\)
**Remark**

- We detected the mass modification in the inv. mass spectra.
- We may exclude some predictions like upward mass-shift.
- Now we ignore:
  - finite-size nuclei <-> infinite nuclear matter
  - Possible time evolution of the density of nuclei in the reaction
    - our model is just toy model...
    - transport calculation like BUU?
  - momentum dependence of 'mass shift' & 'width broadening'
- We expect the precise prediction to be compared with coming high statistics result.
- How can we connect the results with chiral symmetry restoration?
Acknowledgments

• Thank you for the support by all staffs of KEK, including the PS beam channel group, the PS floor staffs, the online group, the electronics division, the computing division and the accelerator division.

• Thanks to the members of Kyoto Univ, RIKEN, etc.
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- Thanks to the members of Kyoto Univ, RIKEN, etc.
- Let's Go to the next experiment at J-PARC!
Backup slides...
Modified shape of $\phi$

- Cu, $\beta\gamma < 1.25$,
- best fit values of $k_1$ and $k_2$
## Summary Table (H.En'yo, YKIS2006)

<table>
<thead>
<tr>
<th>Proton induced</th>
<th>induced (E(\gamma) GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E(_{\text{inc}})</strong></td>
<td>12 GeV</td>
</tr>
<tr>
<td><strong>Exp</strong></td>
<td>KEK</td>
</tr>
<tr>
<td><strong>A</strong></td>
<td>12, 64</td>
</tr>
<tr>
<td></td>
<td>0.18~0.07 g/cm(^2)</td>
</tr>
<tr>
<td><strong>(\phi)</strong></td>
<td>e(^+)e(^-)</td>
</tr>
<tr>
<td>Shift</td>
<td>No hint in IMS. Limits on (\Gamma^*)</td>
</tr>
<tr>
<td>3.4 ±0.6%</td>
<td></td>
</tr>
<tr>
<td><strong>(\omega)</strong></td>
<td>e(^+)e(^-)</td>
</tr>
<tr>
<td>Shift</td>
<td>9.2 ± 0.2%</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(\rho)</strong></td>
<td>Not very sensitive for (\omega) mod.</td>
</tr>
</tbody>
</table>
(experimental effects on the BW shape)

- thick target effect : 1g/cm²
Proposed spectrometer

- Tracking Device
  - GEM (Gas electron multiplier)
    - 0.7mm pitch strip readout
- Two-stage Electron ID
  - Gas Cherenkov
    - GEM + CsI photocathode
      - pad readout
    - Leadglass EMC
- ~70K Readout Channels (in 27 units)
  - E325: 3.6K, PHENIX: ~300K
- Cost: ~$5M (including $2M electronics)
  - 2 times of E325
high mass resolution

- mass resolution should be less than $\sim 10\text{MeV}$

Fast

Slow

(model calc. with $k=0.05/\Gamma=x10/E325$ spectrometer)