Measurements of the low mass dielectron spectra at J-PARC

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- Physics: chiral symmetry in matter
- results of KEK-PS E325
- J-PARC E16 experiment
  - goal
  - Key issues of design
  - R&D status
Chiral symmetry in dense matter

- Origin of hadron mass: spontaneous breaking of chiral symmetry
- In hot/dense matter, chiral symmetry is expected to be restored
  - hadron modification is also expected
  - many theoretical predictions...
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)y
  = 2\sim 4\% for \( \phi \)
  (for \( y=0.22 \))
at the normal nuclear density

Oset and Lamos
NPA 679 (01) 616

\( \phi \) mass shift
< 1\%
width broadening
x5 (22MeV)
at 1020MeV, at \( \rho_0 \)
E325 observed the meson modifications

- in the $e^+e^-$ channel
- below the $\omega$ and $\phi$, statistically significant excesses over the known hadronic sources including experimental effects
E325 : interpretation

- MC type model analysis to include the nuclear size/meson velocity effects
  - generation point : uniform for $\phi$ meson
    - from measured A-dependence
    - measured momentum distribution
    - Woods-Saxon density distribution
    - decay in-flight : linearly dependent on the density of the decay point
      - dropping mass: $M(\rho)/M(0) = 1 - k_1(\rho/\rho_0)$
      - width broadening: $\Gamma(\rho)/\Gamma(0) = 1 + k_2(\rho/\rho_0)$

- consistent with the predictions

\[
k_1 = 0.034^{+0.006}_{-0.007}
\]

\[
k_2^\text{tot} = 2.6^{+1.8}_{-1.2}
\]

- 3.4% mass reduction (35MeV)
- 3.6 times width broadening (16MeV)
  at $\rho_0$
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From “mass modification” to physics

- Mass shape modification of vector mesons in medium looks to be established by many experimental results (E325/CLAS-G7/TAPS at the lower energy, NA60/CERES in HI collision)
  - statements contradict each other
    - mass dropping and/or width broadening
    - depending on the interpretation models to include the matter size effect
  - physics
    - only hadronic effects? or chiral restoration?

- Next step in the invariant-mass approach
  - put an emphasis on $\phi \rightarrow e^+e^-$: less ambiguous
    - $\rho$'s complicated shape, $\rho-\omega$ interference, $\rho/\omega$ ratio, etc.
  - systematic study of the shape modification
    - nuclear matter size dependence: larger/smaller nuclei, collision geometry
    - momentum dependence: predicted, but not measured yet
  - check the validity of the interpretation models
dispersion relation (mass VS momentum)

- S.H.Lee (PRC57(98)927) \( m^*/m_0 = 1 - k \rho/\rho_0 \)
  - \( \rho/\omega \) : \( k=0.16 \pm 0.06 + (0.023 \pm 0.007)(p/0.5)^2 \)
  - \( \phi \) : \( k=0.15(\pm 0.05)\times y + (0.0005 \pm 0.0002)(p/0.5)^2 \)
  - for \( p<1\text{GeV/c} \)

- Kondratyuk et al. (PRC58(98)1078) : \( \rho \) meson

- Post & Mosel(NPA699(02)169) : \( \rho \) meson
---J-PARC E16 experiment---
Low-mass dielectron measurement

- 2007/3: stage1 (physics) approval
- Detector R&D is on going

Collaboration
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S. Sawada, M. Sekimoto
Kyoto-U K. Aoki

Proposal revised version 1 (2006 June 7) is located on:
J-PARC E16 experiment

- Same concepts as KEK-PS E325
  - thin target (0.1% interaction) / primary beam (~10^{10} /sec)/ slowly moving vector mesons in the ee channel
- **Main goal**: collect \( \sim 1\text{-}2 \times 10^5 \phi \rightarrow \text{ee} \) for each target in 5 weeks
  - \( \sim 100 \) times as large as E325
    - new nuclear targets: proton (CH\textsubscript{2} -C subtraction), Pb
    - collision geometry for Pb target (by multiplicity)
- **systematic study** of the velocity & nuclear size dependence of excess ('modified' component)
  - check the interpretation models
  - extract the dispersion relation (momentum dependence of mass)
- mass resolution: keep \( \sim 10 \) MeV
- \( \rho,\omega \) and \( J/\psi \) can be collected at the same time
High momentum Beamline

30/50GeV proton beam (upto 10^{12} /sec)
velocity and nuclear size dependence

- velocity dependence of excesses ('modified' component)
- E325 only one data point for $\phi$ (slow/Cu) has significant excess
velocity and nuclear size dependence

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- establish the modification

NP08 08Mar06 S.Yokkaichi
velocity and nuclear size dependence

- velocity dependence of excesses ('modified' component)
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- systematic study: all the data should be explained the interpretation model

- establish the modification
- check the interpretation model with shape analysis for each histogram
dispersion relation (mass VS momentum)

- prediction for $\phi$ by S.H. Lee ($p<1\text{GeV}$)
- current E325 analysis neglects the dispersion (limited by the statistics)
dispersion relation (mass VS momentum)

- prediction for $\phi$ by S.H.Lee ($p<1$ GeV)
- current E325 analysis neglects the dispersion (limited by the statistics)
- fit with common shift parameter $k_1(p)$, to all nuclear targets in each momentum bin

![Graph showing dispersion relation](image)

- $\phi$ mass (1020)
- $\sim 35$ MeV
- E325
- E16 (for example...)

$N_{\text{excess}} = N_{\text{excess}}^{(N)}$
Key issues/digits for the spectrometer design

- electron ID: $10^{-4} \pi$ rejection
  - suppress the trigger rate and the background from misidentified pions
- low material: 0.5% $X_0$ for each target, 4% $X_0$ for trackers
  - suppress the background from the conversion electron pairs, reduce a tail due to the bremsstrahlung
- high rate capability: 10MHz interactions at targets
  - to collect high statistics in use of primary beam ($\sim 10^{10} /\text{sec}$)
- high mass resolution: less than 10 MeV (rms)
  - to see the modification
  - less than 200um of position resolution of the trackers
experimental effects on the BW shape (E325)

• E325 Detector Sim.
  - target material is negligible for ~0.5% radiation length ($X_0$)
  - detectors: up to 4.5% $X_0$ in the tracking region
experimental effects on the BW shape (E325)

- E325 Detector Sim.
  - target material is negligible for ~0.5% radiation length ($X_0$)
  - detectors: up to 4.5% $X_0$ in the tracking region

- In the case of the thick targets: 1g/cm$^2$
  - bremsstrahlung in target is so large for the Cu case
mass resolution requirement

- mass resolution should be kept less than ~10MeV

(model calc. for the Cu target)
Proposed spectrometer

- Spectrometer Magnet: reuse E325's
  - remodeling the pole / repairing the coil
  - stronger field for compact detector size
- GEM (Gas electron multiplier) Tracker
  - 0.7mm pitch strip readout
- Two-stage Electron ID ($10^{-4} \pi$ rejection)
  - Hadron Blind Detector (Gas Cherenkov)
    - GEM+Csl photocathode
    - hexagonal pad readout (~30mm φ)
  - Leadglass EMC: reuse of TOPAZ
- ~70K Readout Channels (in 26 segments)
  - cf. E325: 3.6K, PHENIX:~300K
- Cost: ~$5M (including ~$2M electronics)
  - cf. E325: $2M not including electronics
Prototype module is under construction

- the spectrometer consists of 26 modules in the conceptual design
Prototype module is under construction

- Items should be tested
  - thin readout boards:
    - Kapton 25um, Cu 4um
    - double sided (x,y) 350um pitch
  - domestic large GEM (300mm x 300mm)
  - alignment of the three GEM chambers
- Parts will be delivered till March 31, test will start in April
Delivered parts (Feb.29)

chamber frames

largest thin read-out board (300x300mm)
Detector R&D status

- GEM: domestic products works well
  - high gain GEM / larger size (300mm x 300mm)

- HBD (Gas Cherenkov using GEM + CsI photocathord)
  - PHENIX prototype / working model
  - In Japan:
    - CsI photocathord (Hamamatsu)
    - CF$_4$ operation
    - Beam test @ HiSOR (Hiroshima-U)
    - long term operation
  - GEM Tracker for high rate
    - Triple GEM w/ 2D double-sided strip read-out board (@U-Tokyo)
    - low material strip read-out board
  - prototype module of the spectrometer
    - Tracker + HBD in real-size

already tested on going construction -> test in JFY2008 (2007/08 Grant-in-Aid)
Summary

- Vector meson measurements in $e^+e^-$ channel at J-PARC E16
  - to investigate the chiral symmetry in dense hadronic matter
- 30 (or 50) GeV primary proton beam ($\sim 1 \times 10^{10}$/sec)
  - especially collect $\sim 10^5 \phi \rightarrow e^+e^-$ for each target in $\sim 5$ weeks (800 hours)
  - operation: 100 times as large as KEK-PS E325's statistics
- New spectrometer using new technology (GEM tracker/HBD)
  - R&D is on going at U-Tokyo and RIKEN w/ grant-in-aid
  - Spectrometer design should be finalized in 2008
- Impact of the experiment
  - systematic study of the vector meson mass modification in various size (0~10fm) of dense matter (nuclear matter)
  - momentum dependence of in-medium mass (dispersion relation)
  - provide the systematic data which motivate to develop new theoretical calculations, including interpretation in the real nuclear matter
Backup slides...
GEM Tracker to cope with high rate

- Expected single rate is too high to use DC
  - origin: beam halo and/or from the interactions at the target
- E325 experience x 10 times
  - 1.8 MHz @ 6° (20mm from the beam) /3.5mm x100mm cell of DC @r=200mm
    - 5KHz/mm² → GEM tracker can be operated (cf. COMPASS exp.)
  - 400KHz @ 60° /4mm x100mm @r=200mm
    - marginal rate for DC operation
- E16
  - Fine segment to cope with the high rate
  - position resolution 0.2mm to keep the mass resolution
  - → GEM Tracker w/ 0.7mm pitch readout
**HBD (Hadron Blind Detector)**

- HBD : Thr. type Gas Cherenkov Counter
  - CsI photocathode : UV photon sensitive
  - Triple GEM with pad readout
  - CF$_4$ is a radiator and amplification gas
  - Ionized electrons are collected by mesh
    - photoelectrons are amplified by 3 stages
    - ionized electrons are amp. by only last 2 stages
    - → can detect only particles with cherenkov photon.
      - (1/100 of pion rejection)
- Joint development with Weitzman Institute
  - originally for PHENIX upgrade plan
- Cover large area with no mirror
- 10cm x 10cm of Trigger tile : effectively fine segmented
  - essential to trigger the e$^+e^-$ pair from the vector meson

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**Concept of HBD**

- CF$_4$ radiator
- Mesh
- CsI photocathode
- GEM
- Pads
- E$_{GEM}$
- E$_{transfer}$
- E=0
To collect high statistics

- For the statistics 100 times as large as $E_{325}$, a new spectrometer is required.
  - To cover larger acceptance: $x \sim 5$
  - Higher energy beam ($12 \rightarrow 30/50$ GeV): $x \sim 2$ of production
  - Higher intensity beam ($10^9 \rightarrow 10^{10}$ /spill (1sec)): $x \times 10$ (→ 10MHz interaction on targets)

Geometrical (horizontal & vertical) coverage of the spectrometer
New nuclear targets with larger statistics

- Smaller nuclear target:
  - proton as reference ($\text{CH}_2 - \text{C}$ subtraction)
  - LH target cannot be used because of the materials

- Larger nuclear target as Pb
  - larger nuclear matter
  - collision geometry (impact parameter) study using multiplicity
  - larger radiation length for heavier target
    → more thinner foil target to keep S/N
  - high statistics capability is required.
Schedule

• (already funded ~ $0.15M)
  - 2007 - 8:
    • prototype spectrometer module
test/design finalize
• (budget dependent ~ $5M)
  - 2008-9:
    • production start
  - 2009-10
    • spectrometer construction at the
counter hall
  - 2011
    • ready for 30GeV proton beam
# Cost estimation

<table>
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<tr>
<th>Detector</th>
<th>element</th>
<th>description</th>
<th>cost [Yen]</th>
<th>cost [M Yen]</th>
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<tr>
<td>GEM Tracker</td>
<td>Frame</td>
<td></td>
<td>820k</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>GEM foil (10x10 [cm²] foil)</td>
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<td>20 k x (1+4+9) x 3</td>
<td>50</td>
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<tr>
<td></td>
<td>readout strip board (10x10 [cm²])</td>
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<td>100 k x 14</td>
<td>38</td>
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<tr>
<td></td>
<td>electronics</td>
<td></td>
<td>3 k/ch x (800 x 2) chs</td>
<td>140</td>
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<tr>
<td>Cerenkov Counter</td>
<td>Frame</td>
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<td>500k</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>GEM foil (11 x 11 [cm²])</td>
<td></td>
<td>20 k x 25 x 3</td>
<td>50</td>
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<td></td>
<td>Cst coat</td>
<td></td>
<td>40 k x 25 foils</td>
<td>27</td>
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<tr>
<td></td>
<td>readout pad board electronics</td>
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<td>3 k/ch x 460 chs</td>
<td>38</td>
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<tr>
<td>Outside Tracker</td>
<td>Frame</td>
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<td>500k</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>readout strip board electronics</td>
<td></td>
<td>20 k x 1000 chs</td>
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</tr>
<tr>
<td>subtotal</td>
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<td>13.5M</td>
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<tr>
<td>EM Calorimeter</td>
<td>lead glass and PMT</td>
<td>reuse from TRISTAN/TOPAZ</td>
<td>0</td>
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</tr>
<tr>
<td></td>
<td>Frame</td>
<td>3 k/ch</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>electronics</td>
<td></td>
<td>2 (650 chs)</td>
<td></td>
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<tr>
<td>Magnet</td>
<td>Return yoke</td>
<td>reuse from E325</td>
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<tr>
<td></td>
<td>Pole piece</td>
<td>transfer from KEK</td>
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<td></td>
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<td></td>
<td>Coil</td>
<td>modification</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>repair</td>
<td>30</td>
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</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>590</td>
<td></td>
</tr>
</tbody>
</table>
beam energy and spectrometer acceptance

A) Reuse of E325 spectrometer
B) Proposed larger acceptance spectrometer

expected $\phi$ yield for two options (using JAM)

<table>
<thead>
<tr>
<th>beam energy</th>
<th>12 GeV</th>
<th>30 GeV</th>
<th>50 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi$ production CS (p+Cu)</td>
<td>1.0 mb</td>
<td>3.0 mb</td>
<td>5.1 mb</td>
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<tr>
<td>detector acceptance</td>
<td>case A</td>
<td>8.8%</td>
<td>6.0%</td>
</tr>
<tr>
<td>case B</td>
<td>45%</td>
<td>31%</td>
<td>23%</td>
</tr>
<tr>
<td>normalized yield by E325</td>
<td>case A</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>case B</td>
<td>5.1</td>
<td>10.0</td>
<td>12.7</td>
</tr>
</tbody>
</table>

10 times can be collected by larger acceptance and beam energy (both 30 and 50 GeV are acceptable)

Further, for 10 times higher intensity beam ($10^{10}$) (i.e. high interaction rate : 10MHz) to collect higher statistics ( $10^5 \phi$ =100 times of E325), new spectrometer is required.
KEK-PS E325

- to observe the vector meson modification in the cold nuclear matter at the normal nuclear density

- $12\text{GeV} \ p + \text{C/Cu} \rightarrow \rho/\omega/\phi + \text{X}$ (\(\rho/\omega/\phi \rightarrow \text{e}^+\text{e}^-, \phi \rightarrow \text{K}^+\text{K}^-\)), $1<p<3\text{GeV}/c$ for $\phi$

- run 1997-2002
History of E325

- 1993 proposed
- 1994 R&D start
- 1996 construction start
- '97 data taking start
- '98 first ee data
  - PRL86(01)5019 \( \rho / \omega \) (ee)
- 99,00,01,02...
  - x100 statistics
  - PRL96(06)092301 \( \rho / \omega \) (ee)
  - PRC74(06)025201 \( \alpha \) (ee)
  - PRL98(07)042501 \( \phi \) (ee)
  - PRL98(07)152302 \( \phi \) (KK),\( \alpha \)
- '02 completed
- spectrometer paper
  - NIM A457(01)581
  - NIM A516(04)390

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