J-PARC E16
Vector meson in nuclear matter

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• physics motivation
• dilepton measurements in the world
• E16 status and plan

Collaboration
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Hiroshima-U K. Shigaki
JASRI A. Kiyomichi
Origin of Mass (Higgs)

Big Bang  \[10^{10}\text{[sec]}/1\text{P}[\text{K}]\]

quark mass

- 0 MeV
- 3 MeV

“resistance”

schematic diagram of vacuum

- Origin of lepton and quark mass: Higgs
Origin of Mass (QCD)

- Origin of lepton and quark mass: Higgs
- Origin of quark and hadron mass: spontaneous breaking of chiral symmetry, originally proposed by Nambu
  - Hadron mass could be modified in hot/dense matter, because of the chiral symmetry restoration is expected in such matter
## Vector meson measurements in the world

- **HELIOS/3** (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) 1-4 GeV p+Au/ 1-2GeV A+A
- **CLAS-G7 (*)** (ee) 1~2 GeV γ+A
- **J-PARC E16** (ee) 30/50GeV p+A
- **HADES/FAIR** (ee) 2~8GeV 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
- **ANKE** (KK) 2.83 GeV p+A

*published/ 'modified'* published/ 'unmodified' running/in analysis future plan as of 2012/Mar
Dilepton spectrum measurements in the world

NA60: ρ width broadening
PHENIX: enhancement (cannot be explained yet)

Chiral restoration at High-T is not confirmed yet

PHENIX

CERES/NA60

HADES/CBM

DLS/HADES

E325/E16

TAPS/CLAS

E325: ρ/ω mass dropping
φ mass dropping and broadening

CLAS-g7: ρ broadening

HADES: low-mass enhancement

Partial chiral restoration at ρ₀ is measured w/
the deeply bound pionic atom

Open question:
Observed hadron modifications are
signature of the chiral restoration / evidence
of the QCD mass generation?
Experimental methods: pros and cons

- leptonic decay VS hadronic decay
  - small FSI in the matter, but small branching ratio
- proton/photon induced VS heavy-ion collision
  - cold VS hot
  - static environment VS time evolution
  - S/N is better, production cross section is smaller
- $\phi$ VS $\rho/\omega$
  - isolated and narrow, but production CS is smaller
- Why only KEK-PS E325 can observe the $\phi$ modification?
  - proton induced: better S/N than the HI collisions
  - large stat. using a high intensity beam: cope with the small CS
  - good spectrometer keeps the good mass resolution and works under the higher interaction rate
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

1) decay inside nuclei
2) decay outside nuclei

expected to be observed
KEK-PS E325

- 12GeV p+A (C/Cu) → ρ, ω, φ in the e⁺e⁻ channel

- below the ω and φ peaks, statistically significant excesses over the known hadronic sources including experimental effects

- interpreted: mass dropping 9.2% (ρ, ω), 3.4% (φ)

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PRL98(07)042501

PRL96(06)092301

ω (783)

Cu

fit result

φ (1020)

Cu

βγ <1.25

bkg subtracted

PRL98(07)042501

[GeV/c²]
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!
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.
Discussion: modification parameters

- MC type model analysis to include the nuclear size/meson velocity effects
  - generation point: uniform for $\phi$ meson
  - from the 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 result with the predictions by Hatsuda & Lee ($k_1$), Oset & Lamos ($\Gamma$)

$k_1 = 0.034^{+0.006}_{-0.007}$
$k_2^{\text{tot}} = 2.6^{+1.8}_{-1.2}$

For $\phi$, 3.4% mass reduction (35MeV) 3.6 times width broadening (15MeV) at $\rho_0$
Vector meson measurements in Heavy Ion Collision

- CERES: (PLB666(2008)425)
  - “broadening by hadronic effect” is favored

- "raw data"
  - resonance subtracted
  - bkg subtracted
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'

\[\text{bkg subtracted}\]

\[\text{bkg & resonance subtracted}\]
Vector meson measurements in Heavy Ion Collision

- PHENIX : (arXiv:0706.3034v1,0912.0244v1)
  - 200GeV /u Au+Au → e^+e^-
  - enhancement below \( \omega \)
  - cannot reproduced by any model at low pT
  - at high pT, thermal photons reproduce

![Graph of vector meson measurements in Heavy Ion Collision](image)

bkg subtracted
HADES

- lower energy HI collisions: \( A+A \rightarrow e^+e^- \)
- DLS data is confirmed, and the puzzle in C+C is resolved by (pp+np)[PLB690(10)118]
- However, Ar+KCl have enhancement over the (pp+np) estimation [PRC84(11)014902]

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\begin{align*}
\frac{1}{N_0} \frac{dN_{\text{corr}}}{dM_{ee}} [1/(\text{GeV/c}^2)]
\end{align*}
\]

- \( ^{12}\text{C}^{12}\text{C} \) 1 AGeV
- \( \frac{1}{2} (\text{pp+np}) \) 1.25 GeV
  \[\alpha_{e^+e^-} > 9^\circ\]

\[
\begin{align*}
\frac{1}{N_0} \frac{dN_{\text{corr}}}{dM_{ee}} [1/(\text{GeV/c}^2)]
\end{align*}
\]

- Ar + KCl 1.76 AGeV
- \( \frac{1}{2} (\text{pp + np}) \) 1.25 AGeV

\([\text{arXiv}:1011.5424v2]\)
HADES 3.5GeV pp and p+Nb

- Selecting slower mesons, an excess is seen below the $\omega$ peak in the larger nuclei data (preliminary)

HADES p+p vs p+Nb @ 3.5 GeV($E_{\text{kin}}/u$)

- strong difference in spectral function for slow pairs in the vm region

(P.Salabura, cracow)
J-PARC E16
J-PARC E16 experiment

- Measure the vector-meson mass modification in nuclei systematically with the $e^+e^-$ invariant mass spectrum

- A 30 GeV primary proton beam ($10^{10}$/spill) / 5 weeks of physics run to collect ~$10^5 \phi \rightarrow e^+e^-$ for each target

- Confirm the E325 results, and provide new information as the matter size/momentum dependence of modification

Proposed exp. E16

- Nuclear matter size dependence of mass modification are measured

Precedent exp.(KEK-PS E325)

- $\phi$-mass is modified in large nuclei for slowly moving mesons... consistent with the prediction based on the QCD sum rule

$\phi$ mass (1020)

- Measured by E325 $\Delta M \sim 35$ MeV

- Expected

- Momentum dependence
To collect high statistics

- For the statistics 100 times as large as E325, a new spectrometer and a primary beam in the High-p line are 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)
  - To cope with the high rate, new detectors (GEM Tracker & HBD) are required.

Proposed Spectrometer

26 detector modules
High-p line in the Hadron hall

- 1x10^10 for E16 (current beam power is enough, only 1% of A-line)

- 3 years plan of the construction: budget requested by KEK to MEXT
\(\phi\)-mass modification at \(\rho_0\):

- (vacuum value: \(m(0)=1019.456\text{MeV}, \Gamma(0)=4.26\text{MeV}\))
  \[m(\rho)/m(0) = 1 - k_1 (\rho/\rho_0), \quad \Gamma(\rho)/\Gamma(0) = 1 + k_2 (\rho/\rho_0)\]
- determined by E325 (PRL98(2007)042581)
  \[\Delta m: -35 (28\sim41) \text{ MeV}, \quad \Gamma: 15 (10\sim23) \text{ MeV}\]
- Hatsuda, Lee [PRC46(1992)34] \(QCD\) sum rule
  \[\Delta m: -12\sim44 \text{ MeV} \quad (k=(0.15\pm0.05)y, y=0.12\sim0.22), \quad \Gamma: \text{not estimated}\]
  \[\Delta m: < -10 \text{ MeV}, \quad \Gamma: \sim45 \text{ MeV}\]
  \[\Delta m: < -10 \text{ MeV}, \quad \Gamma: \sim22 \text{ MeV for } m=1020\text{MeV}, \sim16\text{MeV for } m=985\text{ MeV}\]
- Cabrera and Vacas [PRC 67(2003)045203] OR01+ hadronic
  \[\Delta m: -8 \text{ MeV}, \quad \Gamma: \sim30 \text{ MeV for } m=1020\text{MeV}\]

\[k_1 = 0.034^{+0.006}_{-0.007}\]
\[k_2^{\text{tot}} = 2.6^{+1.8}_{-1.2}\]
**expected shape w/ various parameters**

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- Can distinguish $\Delta m = -35$ or $-10$ MeV
  - $\Gamma = 15$ or 50 MeV

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- Can distinguish $\Delta m = -10$ MeV
  - $\Gamma = 15$ or 50 MeV
### expected shape w/ various parameters

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**Cu**

- $\beta \gamma < 0.5$
- $0.5 < \beta \gamma < 1.25$

**Pb**

- $\beta \gamma < 0.5$
- $0.5 < \beta \gamma < 1.25$

**Blue**: decays inside the half-density radius of nuclei in the MC
momentum dependence

- From the view point of experimentalists
  - many predictions are for the mesons at rest ($p=0$)
    - extrapolation to $p=0$ if it is a simple dependence
- From the view point of theorists
  - dispersion relation of quasi particles are characteristic
  - other effects

- Weldon (PRD40(89)2410)

- Harada & Sasaki (PRC80(09)054912)

- Kondratyuk et al. (PRC58(98)1078)
**Schedule**

- **2007**: stage1 approval
- **2008-2010**: development of prototype detectors w/ Grant-in-Aid (2007-8, 2009-13)
- **2011**: additional parts of the spectrometer magnet, R/O circuit development
  - 1st module of production type (GT and HBD)
    - test using pion beam @ J-PARC
- **2012**: magnet re-construction
  - all the detectors are installed in the magnet
    - production of the detectors/circuits
- **2013**: staged goal of the spectrometer construction (w/ 8 detector modules): ready for the beam
  - (beam power is enough for 10^10 /spill at High-p)
- **2014-15**: production of detector modules (depending on the budget)
**Impact of E16**

- hadron modification are observed in several experiments but interpretation is not converged: “mass dropping or broadening?”
  - theoretically the question is oversimplified: T-dependence, momentum dependence
  - analysis difficulties in $\rho/\omega$ in the dilepton decay channel
  - small statistics and small data sets
- pin down the phenomena for the vector meson in nuclei ($\rho=\rho_0, T=0$) using $\phi$ meson
  - confirm the E325 observation with improved resolution (x2) and statistics (x100)
  - matter-size dependence and momentum dependence will be examined systematically
    - first measurement of the dispersion relation of hadrons in nuclear matter
- establish the QCD effect
  - mass generation due to the chiral symmetry breaking
- Further Step (future experiment)
  - slow $\phi$ at HIHR beam line with $10^9$ $\pi$ beam, $\mu\mu$ pair measurement, etc.
  - higher density state using medium-energy HI collisions
    - chiral phase transition in the high-density region
International competition

- FAIR (GSI upgrade: new accelerator SIS 100 is funded)
  - Two spectrometers for the heavy-ion collisions are funded
    - HADES : 2-8 GeV : start ~2018
      - detectors will be moved from SIS 18 to SIS 100, as the 1st experiment
    - CBM : 15-30 GeV : probe the high-density state
      - newly constructed
  - Detector acceptances for the A+A : relatively forward
    - not suitable to detect slower mesons in p+A reactions
    - however, a clue is seen in 3.5 GeV p+A in HADES
    - design value of the interaction rate ($10^7$Hz) is as high as E16
- We strongly urge the construction start of High-p line
  - If even a part of magnets are constructed in the JFY 2012, they can be aligned in the long shutdown in 2013 and thus the earlier completion is expected.
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This year (JFY) possibly compete with HADES/FAIR
**GEM R&D for Tracker/HBD**

- **GEM Tracker** to cope with the high rate
  - Ar+CO₂(70:30)
  - angled injection, 2D readout, etc.
  - required position resolution 100um is achieved for angled tracks w/ FADC R/O

- **Hadron Blind Detector** to trigger the electrons
  - CsI photocathode, CF₄ gas purity, etc.

- **Domestic Large size (300mmx300mm) GEM**
  - kapton (Polyimide, PI) t=50um for GT
  - LCP, t=100 um for HBD

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![GEM chamber diagram](image)
Beam test results of prototype detectors

GEM Tracker

HBD (Hadron-Blind Cherenkov detector)

- Large size (300x300mm) PI- and LCP-GEM are successfully worked for an electron beam
  - Stability for a pion beam should be checked. : Test @ J-PARC at June.
- GEM Tracker is successfully worked.
- Improvement of the photo-detection efficiency of HBD is on going.

100x100  200x200  300x300

Required position resolution (~100µm) is achieved

UV Cherenkov photons are detected with CsI-evaporated LCP-GEM and CF$_4$ gas

QE upto 40%

10 p.e.
Three types of 2D-R/O board of GEM Tracker

- thin two-dimensional read out board
  - base: t=25 um kapton
  - strip pitch : X: 350 um, Y:350 um
  - required resolution X:100um , Y: 700um
- double side type
  - Y- efficiency is bad (~80%)
- mesh type
  - amplified electrons can reach both X and Y strips by etching-out of base kapton
  - expensive and fragile
- BVH (blind-via-hole) type
  - island electrodes between X strips to transport the electrons to Y strips via holes
  - pitch of Y is changed: 1400um
  - tested in Oct. 2011, works well
GEM Tracker test @ LEPS

1st 100mm x 100mm production type Tracker
- BVH-type R/O board
- Al-mylar cathode
- gas-tight is kept by the GEM frame, Al-mylar and the R/O board
- resolution (efficiency) under the gain=5000
  - 105µm (98%) for X
  - 310 µm (93%) for Y : can be improved by gain=10000

managed by Y. Komatsu & W. Nakai
HBD (Hadron Blind Detector)

- HBD (Thr. type Gas Cherenkov)
  - developed thanks to Weizmann/Stony Brook
  - 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 photons.
      - (1/100 of pion rejection)
  - GEM (LCP 100um: higher gain) by Scienergy.Co.
  - CsI evaporation by Hamamatsu & RIKEN
  - QE improved at RIKEN: beam test at 2011/3
    - 10 photoelectrons detected (cf. PHENIX ~20 p.e.)
    - Improvement of gas purity and GEM HV config. are required
  - Test @ J-PARC in June
    - pion rejection & p.e. improvement

managed by K. Aoki & K.Kanno
Lead Glass from TOPAZ / E362

17 frames were decomposed at KEK warehouse by Y. Aramaki & S. Sekimoto (Apr. 2012)
FM magnet re-modeling

Hadron hall

additional pole piece

delivered in Feb.2012
(managed by R. Muto)

yoke extension
Summary

- Investigation of the hadron spectral modification in nuclear matter is a study of the nature of QCD vacuum
  
  • A major origin of hadron mass is the spontaneous breaking of chiral symmetry and the spectral modification could be a signal of the chiral restoration
  
  • Spectral modification of hadrons is observed in hot (HI collisions) and dense (nuclei) matter in the dilepton invariant mass spectra
  
  • but discussion is not converged: chiral restoration or not

- J-PARC E16 will measure the vector meson modification in nuclei with the ee decay channel, using 30GeV primary proton beam at the High-p line.
  
  • confirm the observation by KEK-PS E325 and provide more precise information of the mass modification
  
  • establish the QCD-originated mass
  
  • preparation is underway
  
  • Staged Goal of construction: the end of JFY 2013
back up
**Spectrometer Magnet re-construction**

- FM magnet (used by KEK-PS E325)
  - additional **poles and yokes**
    - larger acceptance/stronger field
  - decompose -> proper location on the High-p line -> re-construction with **new parts**
  - a pit (digging of the floor concrete) is required under the magnet
    - cannot be managed by Grant-in-Aid: at least, 'overhead' of grants should be used.
  - takes 6-8 months
    - scheduling of the area and overhead crane usage
  - by the end of JFY2012

- detector installation in JFY2013
  - all the detectors are installed in the Magnet
CLAS-G7 (PRC78(2008)015201)

- $\gamma + A \rightarrow V \rightarrow e^+e^-$
- no anomaly for $p > 0.8\text{GeV/c}$

BKG subtracted
CLAS-G7 (PRC78(2008)015201)

- $\gamma + A \rightarrow V \rightarrow e^+e^-$

- no anomaly for $p > 0.8\text{GeV/c}$: $\rho$ mass dropping <4% in 95%C.L.
  - $\rho$ width broadening (up to ~45%) is consistent with the collisional broadening
  - $\omega$ modification is not included in the analysis

BKG subtracted

ρ/ω mass dropping is 9%
CBELSA/TAPS (PRL94(05)192303)

- $\omega \rightarrow \pi^0\gamma \quad (\rightarrow \gamma\gamma\gamma)$
- anomaly in $\gamma + Nb$, not in $\gamma + p$
  - shift param. $k \approx 0.14$

[Graphs and diagrams showing data distributions for $\omega$ decay modes and their distributions in $M_{\pi\gamma}$ for $Nb$ and $LH_2$ targets.]
CBELSA/TAPS

- $\gamma + A \rightarrow \omega \rightarrow \pi^0\gamma (\gamma \gamma \gamma)$
- excess in $\gamma + \text{Nb}$, not in $\gamma + \text{p}$
  [PRL94(05)192303]
- excess is not reproduced significantly by the following experiment
  [EPJA47(11)16]
dispersion of quasi particle in condensed matter

- ARPES (angle-resolved photoemission spectroscopy) measurements
  - Mass acquisition of Dirac electron in the topological insulator
  - heavy electron w/ Kondo-effect in CeCoGe$_{1.2}$Si$_{0.8}$

- Sato et al. (n.phys 7(2011)840)

- Im et al. (PRL 100(2008)176402)
Note: shape and its nuclear matter size / momentum dependence

- size of “mass shift” or “mass dropping” (Δm)
  - proportional to the density : physics
  - could be dependent on the momentum : physics

- number of “shifted” meson
  - proportional to the matter size : experimental viewpoint : use larger nuclei
  - depend on the meson life
    - βγ of mesons : experimental viewpoint: select slower
    - decay width change : physics

- observed shape
  - depend on the “shift”, width, and density distribution of the nuclei
width broadening by absorption

- Attenuation measurements:
  - absorption in nuclei evaluated from the A-dependence of production CS using theoretical models (Glauber, Valencia, Giessen...)
  - additional width: \( \Gamma_{\text{abs}} = \hbar \rho \beta c \sigma_{\text{abs}} \)

- LEPS : \( \phi : \sigma_{\text{abs}} = 35 \text{mb}, p=1.8 \text{ GeV/c} \) [PLB608(05)215] (\( \rightarrow \Gamma \approx 100 \text{ MeV} \))
- TAPS : \( \omega : \sigma_{\text{abs}} = 70 \text{mb}, p=1.1 \text{GeV/c} \), \( \Gamma \approx 150 \text{ MeV} \) [PRL100(08)192302]
- CLAS : \( \phi : 16-70\text{mb}, 2 \text{ GeV/c} \), \( \Gamma = 23\text{-}100\text{MeV} \) [PRL105(10)112301]
  - A-dependence of \( \omega \) (\( p=1.7\text{GeV/c} \)) is not reproduced by any model
- ANKE : \( \phi : 14-21\text{mb}, 0.6\text{-}1.6\text{GeV/c}, 50\text{-}70\text{MeV} \) [arXiv:1201.3517v1]
  - 2.83 GeV p+A

- Note:
  - different from the old higher-energy photo-production data
  - No one measured the width directly through the mass shape
E325 A-dependence of the meson production cross sections

- values for the CM backward
- consistent w/ the former measurement for \(\rho\) meson by Blobel (PLB48(1974)73)
- Nuclear dependence \(\alpha_{\phi} = 0.937\) corresponds to about \(\sigma_{\phi N} = 3.7\)mb (cf. Sibirtsev et.al. EPJA 37(2008)287)

additional \(\Gamma = 12\) MeV for 2 GeV/c \(\phi\) \((\beta = 0.9)\) : consistent with \(\Gamma = 15\) MeV (i.e. \(k_2 = 2.6\))

- Remark:
  \(\Gamma_{\phi} = 15\) MeV at \(m_{\phi} = 985\)MeV is consistent with Oset & Ramos et.al (NPA679(2001)616)