J-PARC E16 experiment and the hadron modification in nuclear matter

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• Contents
  - Chiral restoration and hadron spectral modification in nuclear matter
  - Experiments so far : vector meson (dilepton) measurements
  - J-PARC E16 experiment
Mass and chiral symmetry in nuclear matter

• Origin of quark and 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...

W. Weise, NPA553(93)59
## Vector meson measurements in the world

- **HELIOS/3** (ee, $\mu\mu$) 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** ($\mu\mu$) 400GeV p+A/158GeV In+In
- **PHENIX** (ee,KK) p+p/Au+Au
- **HADES (**)** (ee) 3.5GeV p+A/ 1-2GeV A+A
- **CLAS-G7 (*)** (ee) 1~2 GeV $\gamma$+A
- **J-PARC E16** (ee) 30/50GeV p+A / ~20GeV A+A ?
- **HADES, CBM / FAIR** (ee) 2-8, 8-45 GeV A+A
- **TAGX** ($\pi\pi$) ~1 GeV $\gamma$+A
- **STAR** ($\pi\pi$,KK) p+p/Au+Au
- **LEPS** (KK) 1.5~2.4 GeV $\gamma$+A
- **CBELSA/TAPS(*)** ($\pi^0\gamma$) 0.64-2.53 GeV $\gamma$ + p/Nb

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*published/ 'modified'*
*published/ 'unmodified'*
*running/in analysis*
*future plan*
*as of 2011/Jun*
**Tips**

- **Why Heavy Ion?**
  - Chiral restoration as a signal of QGP (hot matter)
  - Cold dense matter is also investigated using $p+A$ and $\gamma+A$ reactions

- **Why dilepton (lepton pair: $e^+e^-$ and $\mu^+\mu^-$)?**
  - Smaller final state interaction (distortion of spectrum) in nuclear matter is expected than the hadronic decays

- **Why vector mesons?**
  - They decay into lepton pair
  - Other mesons (e.g. $\sigma, \eta, \eta'$ ...) are also investigated
  - Baryons are also important of course

- **Why invariant mass?**
  - Most straightforward
  - Other approaches:
    - Width (interaction CS) from the nuclear transparency ratio
    - Mesic nuclei → next talk by Ohnishi-san
Dilepton spectra in Heavy Ion Collision

- **CERES : e^+e^-** (EPJC 41('05)475)
  - “low mass enhancement” : anomaly at the lower region of ρ/ω
    - in A+A, not in p+A
    - relative abundance is determined by their statistical model
    - Both “broadening” and ”dropping” explain the data

- **NA60 :** (PRL96(06)162302)
  - ρ → µ^+µ^- : 
  - width broadening of ρ
  - state 'BR scaling (mass dropping) is ruled out'

![In-In SemiCentral](image)
**Dilepton spectra in Heavy Ion Collision**

- PHENIX : (arXiv:0706.3034v1,0912.0244v1)
  - 200GeV /u Au+Au → e⁺e⁻
  - enhancement below ω
  - cannot reproduced by any model at low pT
  - at high pT, thermal photons reproduce
Dilepton spectra in p+A : KEK-PS E325

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

- In the e⁺e⁻ channel, below the ω and φ, statistically significant excesses over the known hadronic sources including experimental effects
- The excesses are consistent with “mass dropping” based on the chiral restoration in the normal nuclear matter predicted by Hatsuda and Lee

![Graph showing dilepton spectra](image-url)

PRL96(06)092301

ω (783)

Cu

PRL98(07)042501

φ (1020)

Cu

βγ <1.25
Status of dilepton measurements

- low mass enhancement is found in the dilepton spectra in A+A (in comparison with p+p,p+A) from Bevalac to RHIC energy
  - DLS (Bevalac), Helios/3, CERES(PS).... bad S/N ratio
  - NA60(PS) : width broadening of $\rho$ meson by hadronic calculation
  - PHENIX(RHIC) : not explained theoretically yet

- lower energy elementary reactions: finite density, better S/N
  - modification of resonance is found in dilepton spectra
    - E325(KEK-PS) : consistent w/ mass dropping in partial chiral restoration
    - CLAS-g7(JLab) : consistent w/ hadronic calc. (collisional broadening of $\rho$)

- Modification is observed, but discussion on the physics underlying the observed modification is not converged
  - hadronic many-body effect? chiral symmetry restoration?
  - interpretation model dependence?
    - Assumption of the space-time evolution of the $(T, \rho)$ of matter in the real world
Next step

- In the invariant-mass approach
  - $\phi \rightarrow e^+e^-$: less uncertain than the $\rho/\omega$ case
    - $\rho$'s broad and complicated shape, $\rho-\omega$ interference, $\rho/\omega$ ratio, etc.
  - systematic study of the mass modification
    - matter-size dependence: larger/smaller nuclei, impact parameter
    - momentum dependence: never measured
  - check the interpretation models

- Mesic nuclei approach
  - the deeply bound pionic atom: success to deduce the chiral condensate in nuclei
  - static system: no space-time evolution
  - measure the decay of meson if possible: only inside-decay
  - another physics?
    - high density(K), chiral partner of N ($\eta$)
J-PARC E16 experiment

- Main goal: collect $\sim 1-2 \times 10^5 \phi \rightarrow e^+e^-$ for each target in 5 weeks using 30 (or 50) GeV $p + A$ (C/CH$_2$/Cu/Pb) reactions

  - statistics: $\sim 100$ times as large as E325
  - systematic study of the modification
    - velocity & nuclear size (0~10 fm) dependence
      - proton/Pb targets / collision geometry (impact parameter)
    - momentum dependence (dispersion relation)
  - mass resolution: $\sigma < 10$ MeV (E325: 10.7 MeV for $\phi$)
    - double peak structure can be seen w/ $\beta\gamma < 0.5$, $\sigma \sim 5-6$ MeV
  - $\rho, \omega, J/\psi$'s also can be measured at the same time
  - Confirm the modification observed in E325, and provide new information about the mass of hadrons
E16 : mass resolution requirement

- mass resolution should be kept less than ~10MeV
- Very ideal case: very slow mesons w/ best mass resolution:

\[ \Phi(1020) \]
\[ Cu \]
\[ \beta\gamma < 1.25 \]

\[ \beta\gamma < 0.5, \sigma = 5 \text{ MeV} \]

(E325 data )

(model calc. )
E16 : dispersion relation (mass VS momentum)

- prediction for $\phi$ by S.H.Lee($p<1\text{GeV/c}$)
- 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
E16: schedule

• 2007: stage 1 (scientific) approval
• 2008-2010: development of prototype detectors
  • GEM Tracker and HBD
  • w/ Grant-in-Aid (2007-8, 2009-13 ($2.4M))
• 2011: additional parts of the spectrometer magnet, R/O circuit development
  • budget of beamline construction (2012-14) is requested by KEK
• 2013: Goal of the spectrometer construction

Collaboration
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E16: Beam test results of prototype detectors

GEM Tracker:
Required position resolution (~100µm) is achieved with large-size PI-GEM (300mm x 300mm)

Hadron-Blind Gas Cherenkov detector
UV Cherenkov photons (10 photoelectrons) are detected for an electron track with CsI-evaporated LCP-GEM and CF$_4$ gas
Summary

- Investigation of the hadron spectral modification in nuclear matter
  - is a study of the origin of mass (spontaneous breaking of the chiral symmetry, and its possible restoration)
  - i.e., a study of the nature of QCD vacuum
- Spectral modification of hadrons is observed in hot/dense nuclear matter through 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.
  - confirm the observation by KEK-PS E325 and provide more systematic information of the mass modification
  - Goal of spectrometer construction: the end of 2013
Backup slides...
- 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

**History of E325**

E325 spectrometer located at KEK-PS EP1-B primary beam line
E325 $\phi$ 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.