Electron pair spectrometer to study the meson modification

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• Physics: Chiral symmetry in nuclear matter
• Recent results of KEK-PS E325: $\rho/\omega/\phi \rightarrow e^+e^-$
• Proposed Experiment & Spectrometer at J-PARC
• Detector R&D status
Chiral symmetry restoration in nuclear matter

- Spontaneous CS braking is the origin of hadron mass
- confine-deconfinement phase transition is related with chiral transition
- In hot/dense matter, chiral symmetry is expected to restore
  - hadron modification is expected in such matter
    - HI collision
  - quark-antiquark condensate (order parameter) ~2/3 even at the normal nuclear density, T=0
    - 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, Keiser & Weise ('97), Muroya, Nakamura & Nonaka ('03), etc.
mass decreasing
~16% for $\rho/\omega$
~2-4% for $\phi$
at the normal nuclear density

(Lee also predicted
the momentum dependence
of mass decreasing)
Vector meson measurements

• Leptonic decay channel
  - **HELIOS** (ee, μμ)  450GeV p+Be / 200GeV A+A
  - **CERES** (ee)  450GeV p+Be/Au / 40-200GeV A+A
  - **E325** (ee,KK)  12GeV p+C/Cu
  - **PHENIX** (ee,KK)  p+p/Au+Au
  - **NA60** (μμ)  400GeV p+A/158GeV A+A
  - **HADES** (ee)  4.5GeV p+A/ 1-2GeV A+A
  - **J-PARC** (ee)  30/50GeV p+A / ~20GeV A+A
  - **CBM (GSI)** (ee)  8~40GeV A+A

• Hadronic decay channel
  - **TAGX** (ππ)  ~1 GeV γ+A
  - **STAR** (ππ,KK)  p+p/Au+Au
  - **LEPS** (KK)  ~2 GeV γ+A

  red : state modification  
  blue : not state/in analysis  
  green: future project

NP04  S.Yokkaichi  04Aug04
Vector meson measurements in HI collisions

- STAR: 'shift' in p+p & A+A peripheral (nucl-ex/0307023)
  - relative abundance is free parameter/shape is BWxPS
  - ~770MeV

- CERES:
  - anomaly in A+A, not in p+A
  - relative abundance is determined by their statistical model

NP04  S.Yokkaichi  04Aug04
Expected signal in $p+A \rightarrow e^+e^-$ channel

- smaller FSI in $e^+e^-$ decay channel
- double peak or tail-like structure
  - second peak is made by inside-nucleus decay (modified meson)
  - larger nuclei / slowly moving mesons are expected to have larger 'peak(tail)'
- comparison of $\rho$ and $\phi$
  - $\rho$ (770) & $\omega$ (783):
    - larger production cross section
    - larger decay prob. inside nuclei
    - cannot distinguish $\rho$ & $\omega$ in $e^+e^-$
  - $\phi$ (1020): narrow width
    - smaller decay prob. inside nuclei
    - smaller production cross section
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. 10⁹ ppp -> 10⁶Hz interaction)
  - Large acceptance spectrometer to detect slowly moving mesons, which have larger probability decaying inside nuclei (1<βγ<3)

Collaboration

(Cont'd)

- History of E325
  - 1996 const. start
  - '97 data taking start
  - '98 first ee data
    - PRL86(01)5019
  - 99,00,01,02....
    - x100 statistics
      - presented today
  - '02 completed
  - spectrometer paper
    - NIM A516(04)390
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
Experimental setup - Detectors

Electron ID counters
- Gas Cherenkov & Lead Glass EMC
- total $3 \times 10^{-4}$ π rejection with 78% e efficiency in two-stage operation

Tracker
- Three Drift Chambers

Kaon ID counters
- Aerogel Cherenkov & TOF
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 $e^+e^-$:
  - $\rho/\omega/\phi \rightarrow e^+e^-$, $\omega \rightarrow \pi^0e^+e^-$, $\eta \rightarrow \gamma e^+e^-$
  - 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 the fitting

- **excess** at the low-mass side of $\omega$ (0.6~0.75 GeV)
- $\rho$–meson component seems to be **vanished**!
E325 $e^+e^-$ spectra (BKG subtracted)

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

- However, $\frac{\rho}{\omega} \sim 1$ in former experiment ($p+p$, 1974) ............ suggests the excess is from modified $\rho$ mesons
Discussion: Toy model including modification

- Assumptions to include the nuclear size effect in the fitting shape
  - meson fly through the nucleus, decay with modified mass if the decay point is inside nuclei
    - meson production point: incident surface of nuclei
    - meson momentum: measured distribution in our experiment
    - nuclear density distribution: Woods-Saxon type

- 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)
- \( \rho/\omega \) 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
E325 $e^+e^-$ spectra of $\phi$ meson (BKG not subtracted)

Clear peak is already seen, over 1000 of $\phi$ s for each target, in 2001/02 all statistics

• careful and precise analysis is on going

work in progress
Proposed Experiment at J-PARC
Proposed Experiment at J-PARC

- Same concept as E325
  - thin target / primary beam \((10^9 \sim 10^{10} \text{ ppp})\)/ slowly moving mesons

- **Main goal**: collect \(10^4 \sim 10^5 \phi \rightarrow ee\) for each target in 100 shifts
  - 10-100 times as large as E325
    - velocity dependence of 'modified' component
    - new nuclear targets: proton \((\text{CH}_2 - \text{C subtract}), \text{Pb}\)
  - narrow width \(\rightarrow\) sensitive to modification
  - free from \(\omega - \rho\) interference

- \(\omega, \rho\) and \(J/\psi\) can be collected at the same time
  - higher statistics of \(\omega, \rho\) than E325 with differ A targets
  - 100-1000 \(J/\psi\) are expected in 50GeV operation

- Normal nuclear density \((p+A)\)
  - but also high matter density \((A+A, \sim 20\text{GeV/u})\) in the future
Spectrometer : two options

A) Reuse of E325 spectrometer
or
B) Newly constructed larger acceptance spectrometer

using Gas Electron Multiplier (GEM) as a Cherenkov photon sensor and/or tracker

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

- Tracking Device
  - Drift Chamber
  - GEM (Gas electron multiplier)
    - strip readout
- Two-stage Electron ID
  - Gas Cherenkov
    - PMT+2 mirrors
    - GEM+CsI photocathode
      - pad readout
  - Leadglass EMC
- ~30K Readout Channels (in 20 units)
  - E325: 3.6K, PHENIX:~300K
- Cost: ~$5M (including $2M electronics)
Challenges in Detector R&D

• Environment with high intensity beam: \((10^9 \sim 10^{10} \text{ ppp})\)
  high interaction rate (1-10MHz)
  beam halo is origin of trigger background/saturation of forward detector
  spot size: \(~1\text{mm}\)

• Tracking detector should cope with high intensity beam/high int. rate
  - Drift Chamber
  - GEM and strip read out for tracking detector
    • No drop of gain up to particle flux of \(~10\text{KHz/mm}^2\) (E325 highest is 0.5KHz/mm^2)

• High performance electron ID counter: \(\pi\) rejection \(~10^{-4}\)
  - Leadglass EMC recycled from TRISTAN: < 10^{-1}
  - Gas Cherenkov: \(~10^{-3}\)
  - advantages of GC with GEM-CsI photocathode and pad readout (HBD: hadron blind detector)
    • No mirror and No segment. \(-\rightarrow\) No photon loss with reflection at mirrors
    • Less materials.
    • Flexible trigger configuration with pad readout.
Detector R&D status
GEM R&D at CNS, U-Tokyo

- GEM foils and CsI photo cathode
  - Originally, made in CERN. Recently, Fuchigami Micro co. and 3M produce GEM foils.
  - R&D program is on going at CNS, Weitzman, and BNL.
    - mainly for the PHENIX upgrade program.
  - Check the feasibility
    - Basic parameters (Gain, Quantum Eff. and so on)
    - long term stability
- Results from CNS
  - Produce GEM foils
    - Collaborate with Fuchigami co.
    - Use plasma-etching method.
    - Compare gain with CERN’s foils.
  - We have established the scheme for making foils.
    - Checking for gain stability should be done soon.
  - Produce GEM foils with CsI cathode
    - Collaborate with Hamamatsu co.
HBD (Hadron Blind Detector)

- HBD : Thr. type Gas Cherenkov Counter
  - CsI photocathode : UV photon sensitive
  - Triple GEM with pad readout
    - low granularity/low gain
    - 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.
- Joint development with Weitzman Institute
  - originally for PHENIX upgrade
  - GEM with CsI
    - made in CERN and also in Japan are tested
- beam test was done in this May at KEK
Beam test at KEK (2004/May)

setup at KEK-PS π2 beam line

GEM(CNS)
Beam Test at KEK

- detector response for $\pi$ and electron are tested
- Two detectors
  - Weitzman
  - CNS

Response of Weitzman detector

- ADC spectrum for $\pi$ is very consistent with Energy loss in Gas.
- Electron produces more (photo-)electron than $\pi$.
  - However, it is smaller than expectation. Still, we’re investigating this problem.

Further analysis is underway. Please see K.Ozawa’s talk in JPS.
Summary

• Measure the vector meson modification in nuclear matter to investigate the chiral symmetry in QCD

• E325-type experiment at J-PARC
  - use primary proton beam \((1\times10^9 \sim 1\times10^{10} \text{ /sec})\) on thin targets \((\sim 0.1\% \text{ int.length})\) to reduce electron background
  - especially collect \(10^4 \sim 10^5 \phi \rightarrow e^+e^-\) in p+A reaction in 100shift(1month)
    • (10-100 times as large as E325's statistics)
  - Using old E325 spectrometer, 2-3 times larger statistics than E325 with 30~50GeV proton beam

• New spectrometer using new technology (GEM tracker/HBD)
  - better mass resolution : \(\sim 5 \text{ MeV/c}^2\)
  - larger acceptance -> 10 times larger statistics.
  - higher rate capability -> more 10 times stat. using higher intensity beam

• Test Detector with new technology is being developed. Beam test was done and also planned in next year.