Electron pair spectrometer at the JHF 50-GeV PS to explore the chiral symmetry in QCD

Satoshi Yokkaichi[*], Kyoichiro Ozawa[†]and Shin'ya Sawada[‡]

December 31, 2002

1 Introduction

The spontaneous breaking of the chiral symmetry is playing an essential role in QCD. Effective quark mass which constitutes hadrons is due to the braking. In hot (finite temperature) and/or dense (finite density) matter, the chiral phase transition takes place and the broken symmetry is restored. It is predicted by Lattice QCD that the deconfinement of quark and the chiral phase transition would occur at the same temperature. Quark condensate $\langle \bar{q}q \rangle$ is an order parameter of the chiral phase transition. As temperature (density) increases, the absolute value of $\langle \bar{q}q \rangle$ decreases and finally goes to zero at the critical temperature (density). Unfortunately $\langle \bar{q}q \rangle$ itself is not an observable, however, the spectral properties of hadrons like the mass and the decay width are expected to change sensitively to the $\langle \bar{q}q \rangle$ value. Namely the property of hadrons in the hot/dense matter is a good measure of the chiral symmetry restoration in the matter.

There have been many theoretical approaches to this problem[1] and some experiments already detected the modification of hadron in nuclear matter. At high temperature, the CERES experiment at CERN observed the change of low-mass e^+e^-spectra which suggests the modification of vector mesons in heavy-ion collision[2]. The authors carried out the KEK-PS E325 experiment[3, 4, 5], which measured the $e^+e^-$and K^+K^-decay of light vector mesons ($\rho/\omega/\phi$) made by the proton induced reaction in the target nucleus. We also detected the modification of the vector-meson invariant mass spectra in the e^+e^-channel with higher mass resolution than CERES. It suggests that the spectral change of vector mesons at the finite baryon density. TAGX at INS (KEK-TANASHI) detected the ρ meson modification in $\pi^+\pi^-$channel in γ + ^{3}He reaction[6]. In $\pi^+\pi^-$channel, the data measured by CHAOS at TRIUNF[7] suggested the modified σ meson in various nuclear targets made by the pion induced reaction. CB at AGS[8] also reported similar effect in $\pi^0\pi^0$channel. The existence of the hadron modification has been established in these experiments. However, the origin of the modification is not clarified yet. There are also many explanation unrelated the chiral symmetry.

---

[*] RIKEN / contact person : `yokkaich@riken.go.jp`

[†] CNS, University of Tokyo

[‡] KEK

Here we propose to construct a spectrometer at "multi-purpose high momentum beam line" at JHF 50-GeV PS. At first, the aim of the spectrometer is a measurement e^+e^-pair from the p+A reaction to investigate the chiral symmetry around the normal nuclear matter density as same as E325, with higher statistics and higher resolution. When heavy-ion beam is available in JHF, we can explore the chiral symmetry in higher density, which may be highest density in humankind have ever made on earth. Measurement of J/ψ, K*, D, σ and so on using this spectrometer with some upgrading should be discussed. By such measurements of various hadrons in same density environment, we will have deeper insight into modification of hadrons and further, the chiral symmetry and QCD itself.

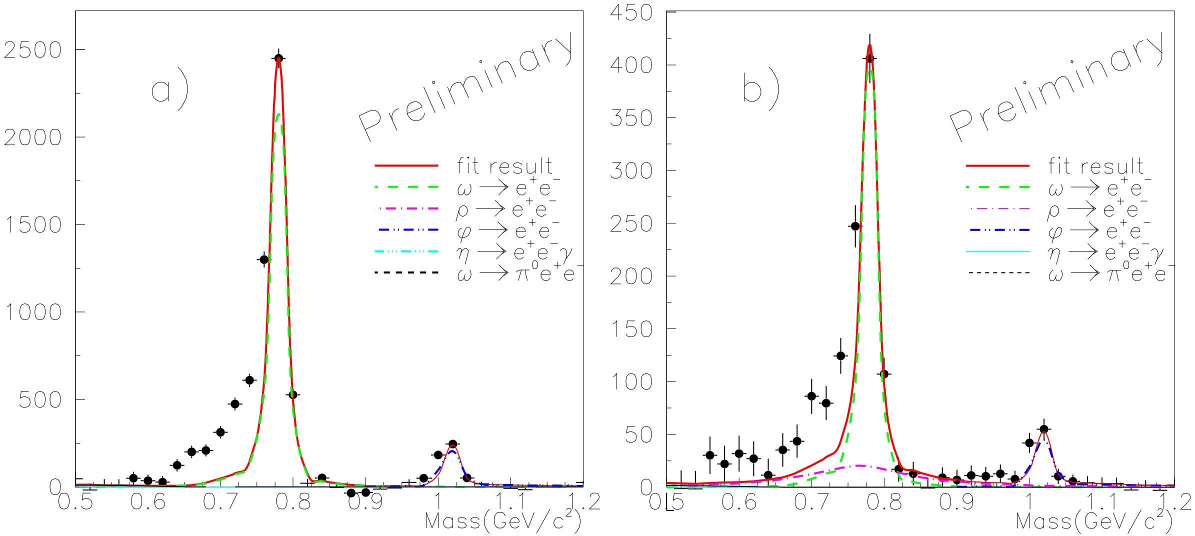
2 Hadrons in finite density

As described in previous section, both the finite temperature and the finite density environment are important to investigate the chiral symmetry in QCD. In JHF, we put the emphasis on the latter environment. The proton (or secondary beam hadron) induced reactions make mesons in target nucleus, which bring the information of the environment around normal nuclear density. Heavy ion collisions around 20∼25 GeV/nucleon are expected to achieve the high baryon density 5∼10 times as large as the normal nuclear density. Of course such energy region was investigated by the AGS (∼ 12 GeV/nucleon) and recently SPS (20 ∼ 30 GeV/nucleon) heavy ion experiments, however, these experiments did not use the electron probe, which less interact in final state. Only GSI future project is competing with us in this energy region.

The chiral symmetry restoration in finite density has been studied in many theoretical methods. Hatsuda and Lee studied using the QCD sum rule and calculate the mass of $\rho/\omega/\phi$ mesons and predicted 10∼20% decreasing for ρ/ω and 2∼4 % for ϕ at normal nuclear density[9]. Hayashigaki studied the mass of J/ψ and D meson also using QCD sum rule and predicted about 0.1∼0.2% decreasing for J/ψ and 2∼3% for D meson also at the normal nuclear density[10]. Some trials using lattice QCD have been made recently although such approaches using lattice for the finite density is more difficult than for the finite temperature. For example, Muroya, Nakamura and Nonaka calculated the mass of π and ρ mesons in finite chemical potential, and found the mass of ρ decreases as the chemical potential increases in the two-color QCD[11].

KEK-PS E325 has been detected the modification of vector-meson spectra using e^+e^-decay. As shown in Fig.1 from the reference[5], we have collected more 100 times of statistics as large as already published results[3]. Significant excesses are found in the low-mass side of the usual ω(783) peak, which cannot be explained using known hadronic sources. The ω mesons have a longer life (∼24 fm) relatively than ρ meson (∼1.3 fm). Therefore more than 90% of ω are expected to decay in free space outside nucleus in which it is created and make such clear peak around 780 MeV/c^2 . The excess could be made by 'modified' ρ mesons decayed in nuclei. Some model calculation based on various 'shift' models are in progress to explain the excesses. Despite premature analysis, a hint of the modification for ϕ mesons can be seen. In this experiment, typically we used the 1×10^9/spill of primary beam and very thin targets whose interaction length was around 0.1∼0.2 % to reduce the electron background from the γ conversion. Data taking was completed on the March, 2002.

In addition to such data collected by the recent experiments, following can be achieved by the



carbon target *copper target*

Figure 1: Invariant mass spectra in e^+e^-channel observed by E325. a) is for carbon target and b) is for copper target.

experiment we proposed. When we have higher statistics we can deduce the kinematic dependence of the modified mesons. We can find the difference of spectra between the data samples of low and high momentum since slowly moving mesons take longer time in nuclei and they are expected to modified stronger than the faster moving mesons. We also can deduce the e^+e^-spectra from pp reaction by CH_2-C subtraction using these targets with higher statistics. Heavier targets like Pb and Au are interesting since the larger size of nuclei bring the larger and clearer signal of the modification. Higher mass resolution enable to distinguish the possible tail of modified ϕ mesons from the background.

3 Proposed spectrometer

We have two options on the proposed spectrometer at the first stage, namely e^+e^-measurements in proton induced reaction. In both case, the experiment is based on the same concept as E325 experiment: using thin targets ($\sim$ 0.1 % interaction) to reduce the electron background from the γ conversion in target materials, high intensity beam to cope with the thin target and small branching ratio, large acceptance spectrometer covering the backward in CM system to detect the slowly moving mesons.

One option is reuse the E325 spectrometer as shown in Fig.2 (case A), which is located at the EP1-B beam line in KEK-PS North Counter Hall. Other option is to build new electron ID counters to cover wider acceptances (case B) as shown in Fig.3. In both case, we would use the spectrometer magnet used by E325. In case B, new electron ID counters consist of highly segmented gas Čerenkov counter and EM calorimeter. As the photon detector for the gas Čerenkov counter, it is discussed to adopt the Gas Electron Multiplier (GEM), which is being developed for the PHENIX upgrade plan. The EM calorimeter segmented finer than E325 gives us a γ identification capability, thus the detection of the radiative decay of K^* and σ mesons comes into the scope. In this case, some vertical extension of the return yoke is also required to locate the new detectors. At a second stage we use the heavy-ion beam and investigate the chiral symmetry in the high density matter. We intend to design the 'case B' spectrometer to work under the high multiplicity environment due to the heavy-ion collision.

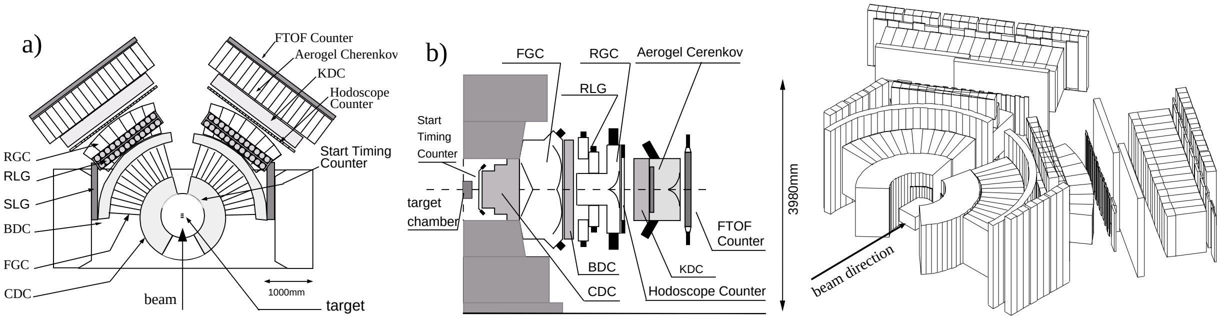


Figure 2: KEK–PS E325 Setup (case A). The left panel is a top view, middle is a vertical cross section and the right is a bird's-eye view.

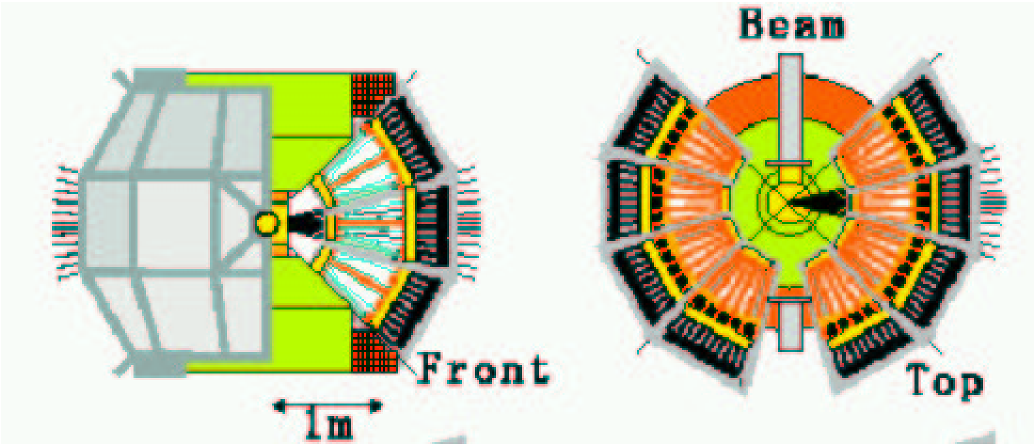


Figure 3: Schematic view of the proposed new spectrometer (case B). The left panel is a front view and the right is a plan view (horizontal cross section at the center).

We estimated a yield of ϕ mesons in e^+e^- decay mode. As same as E325 experiment, if we can collect enough statistics for ϕ, we also can expect to collect the ρ/ω mesons about 10 times as much as ϕ. We used the nuclear cascade code JAM[12] to estimate the production cross section and the kinematical distribution of ϕ meson in p+A reactions. It should be noted that the predictions by JAM are consistent with the results of 12 GeV p+A reaction measured by E325, in the kinematical distribution of ϕ meson and even in the absolute production cross section within factor 2. It was also confirmed that the incident-energy dependence of the predicted cross section by JAM is consistent with the phenomenological scaling law about production cross section of narrow vector mesons in pp reaction[13].

Here, we discuss p + Cu reaction at 12 GeV, 30 GeV and 50 GeV of incident kinetic energies. The beam energy 30 GeV is planned at the Phase 1 of JHF, while 50 GeV is available at the Phase 2. Cross sections are scaled by the measured value at 12 GeV. Two detector geometries mentioned above are considered. The 'case A' covers $\pm 23^\circ$ vertically and from $\pm 12^\circ$ to $\pm 90^\circ$ in the left and right side. In the 'case B' the vertical acceptance is enlarged to $\pm 45^\circ$, the horizontal acceptance is $0^\circ \sim \pm 90^\circ$ except the very forward region of $0^\circ \sim \pm 12^\circ$ both vertically and horizontally to avoid beam halo.

The results are shown in Table 1. At 30 or 50 GeV the production cross sections are 3∼5 times larger than 12 GeV, on the other hand the Lorentz boost decreases the detector acceptances for the $\phi \to e^+e^-$ detection. Therefore the effective yields are only 2∼2.5 times when we use the case A, the same setup as E325. However, the yield increases by factor 13 when we introduce the case B. Taking into account that typically $\sim 1\times10^9$/spill is the beam intensity used by E325, our yield could be 100 times as large as E325 when we build the spectrometer which works under the $\sim 1\times10^{10}$ proton/spill and $\sim 1\times10^7$ interaction/spill. For such high intensity operation, beam quality is an important issue as considered later.

beam energy		12 GeV	30 GeV	50 GeV
production cross section		1.0 mb	3.0 mb	5.1 mb
detector acceptance	case A	8.8%	6.0%	4.5%
	case B	45%	31%	23%
normalized yield by E325	case A	1	2.0	2.6
	case B	5.1	10.0	12.7

Table 1: The ϕ meson yield in p + Cu reactions for two geometries.

In case B, assuming the same detector/trigger/analysis efficiency and the same beam intensity ($\sim 1 \times 10^9$) as E325, around 100 shifts of machine time for production run is required to collect the statistics 10 times as large as E325.

4 Requirements for the beam line

We will use primary proton beam of $1\times10^8 \sim 1 \times 10^{10}$ / spill (assuming 1 sec of duration in 3 sec cycle), typically 1×10^9 / spill. The beam spot size of less than 10 mm is acceptable and around 1 mm is desirable from a view point of the target(s) configuration. Less than 1 mm is not necessary taking account of heat deposit on thin targets. The main trigger background in E325 was electrons flying from upstream whose origin may be collisions between the beam halo and materials around the beam line. For 1×10^9/spill of intensity, particle density at the point 20 mm apart from the beam line was about 3.5×10^5/spill measured by a drift chamber with 3.5 mm of the cell width and 220 mm of height ($\sim 5 \times 10^4$/1 mm(w)/100 mm(h)). At the point of 80 mm apart from the beam, about 10^6/spill was counted by a scintillation counter with a width of 40 mm and a height of 400 mm ($\sim 6 \times 10^3$/1 mm(w)/100 mm(h)). Desirable halo rate is less than 10% of mentioned above since 10^{10}/spill of beam is in the scope.

The spill structure and the long time stability of intensity are another problem. In KEK-PS EP1-B beam line, it was difficult to deliver the time-stable beam in the operation of the double slow extraction from the main ring. It was usual the factor two of intensity drifting in an hour and sometimes changed by factor 10. The spill structure itself was changed in several hours, the shape was usually slant and intensity difference between the begin and end of the spill was about factor two. These instabilities were the origin of the wire breakage of drift chambers.

This spectrometer covers mainly the target region to detect the slowly moving mesons, thus the forward region is opened. Therefore the spectrometer can share the beam line with other spectrometer covers the forward region. It is not favored to share the beam line with a spectrometer just upstream of us, taking account of the electron background mentioned above.

5 Available resources and funds

The detectors made and used by the KEK-PS E325 experiment may be available in principle while the electronics and the power supplies used in the experiment are properties of the KEK circuit group. Especially, the spectrometer magnet and the power supply for it can be reused. To achieve the wider acceptances for 'case B', the return yoke should be extended vertically.

We have applied the Grant-in-Aid for Scientific Research of the Japanese MEXT and JSPS to prepare this experiment.

6 Summary

We propose the construction of the spectrometer to measure the electron pair for investigation of the chiral symmetry restoration in the finite density matter through the meson modification. At the first stage, proton induced reactions are used to investigate around the normal nuclear density. At the second stage, heavy-ion beam is used to explore the high baryon-density state. The reuse of the E325 spectrometer is one idea at the first stage, while statistics is not so larger than the current experiment and the impact of the data would be relatively small. For definitely higher statistics and higher resolution than achieved by current experiments, it is necessary to construct the new electron ID counters and trackers to cope with the expected high intensity beam, high interaction rate and high multiplicity interaction. To investigate the high density state, the probe should not be limited to the electron. We should consider γ /muon capability or extendability when we design the new spectrometer.

A Expected secondary-beam intensity

The other consideration was made to use the secondary beam, for example $\sim$10 GeV/c K^-. They may have a larger production cross section than the proton induced reaction. If available intensity is around 10^9 /pulse, larger cross section means higher yield of ϕ meson. However, expected intensity is too low to use for such experiment as proposed in this letter.

To estimate the intensity of the secondary beam, we used the Sanford-Wang[14] formula for the secondary particle production. We have assumed the beam-line parameter as shown in Table

2 for Phase 1 of JHF, and the results are shown in Table 3. We obtained that for 3 GeV/c $\sim$ 12 GeV/c K^- the available intensity is only about 10^5/pulse. In Phase 2, higher intensity and energy of the 50 GeV primary beam will bring about 10 times larger secondary intensity.

incident energy	30 GeV
primary intensity	1×10^{14} proton/pulse
production angle	4.7°
acceptance	0.2 msr·%
target loss	2%
length	120 m

Table 2: The beam line parameter for the secondary beam estimation.

secondary beam	number at target (per 10^{14} proton)	survival factor of 120m flight
12 GeV/c π^-	1.2×10^6	84%
12 GeV/c K^-	0.07×10^6	26%
6 GeV/c K^-	1.1×10^6	7%
3 GeV/c K^-	1.2×10^6	0.5%

Table 3: The secondary beam intensity.

References

[1] T. Hatsuda and T. Kunihiro, Phys. Rep. **247** (1994) 221, G.E. Brown and M. Rho, Phys. Rep. **269** (1996) 333

[2] G. Agakichiev *et al*., Phys. Lett.**B422** (1998) 405

[3] K. Ozawa *et al*., Phys. Rev. Lett **86** (2001) 5019

[4] S. Yokkaichi *et al*., AIP Conf. Proc. **610** (2002) 551

[5] M. Naruki *et al*., Nucl. Phys. **A** (2003) (to be published as the PANIC 02 proceedings)

[6] M.A. Kagarlis *et al*., Phys. Rev. **D60** (1999) 025203

[7] F. Bonutti *et al*., Nucl. Phys. **A677** (2000) 213

[8] A. Starostin *et al*., Phys. Rev. Lett. **85** (2000) 5539

[9] T. Hatsuda and S.H. Lee, Phys. Rev. **C46** (1992) R34

[10] A. Hayashigaki, Prog. Theor. Phys **101** (1999) 923 A. Hayashigaki, Phys. Lett. **B487** (2000) 96

[11] S. Muroya, A. Nakamura and C. Nonaka, `hep-lat/0211010`

[12] Y. Nara *et al*., Phys. Rev. **C61** (1999) 024901

[13] D. Drijard *et al*., Z. Phys. **C9** (1981) 293

[14] J.L. Sanford and C.L. Wang, BNL reports No 11299 & 11479(1967)