E16 Status & Plan as of 2013/9

Proposal title:
Electron pair spectrometer at the J-PARC 50 GeV PS
to explore the chiral symmetry in QCD

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- physics motivation
- experiment
- progress in the detector development
- schedule
- summary

Collaboration

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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 spectral modification is also expected
  - many theoretical and experimental approaches
- Hadron modification is observed in many experiments, but the origin is not determined
  - NA60(PS), PHENIX(RHIC) : \( \rho \) and/or low mass
  - CLAS-g7(JLab) : \( \rho \)
  - E325(KEK-PS) : \( \rho/\omega \), and \( \phi \)
- best mass resolution and high statistics
- Next Step ...
  - put an emphasis on \( \phi \) : not ambiguous like \( \rho/\omega \)
Dilepton spectrum measurements in the world

- NA60: $\rho$ width broadening
- PHENIX: enhancement (cannot be explained yet)
  
  *Chiral restoration at High-$T$ is not confirmed yet*

- E325: $\rho/\omega$ mass dropping
- PHENIX: $\phi$ mass dropping and broadening

- HADES/CBM
- CLAS-g7: $\rho$ broadening
- HADES: low-mass enhancement
  
  *Partial chiral restoration at $\rho_0$ is measured with the deeply bound pionic atom*

Open question:
Observed hadron modifications are signature of the chiral restoration / evidence of the QCD mass generation?
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 $\sim 10^5 \phi \rightarrow e^+e^-$ for each target with an improved mass resolution, 5MeV.

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

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

Proposed exp. E16

Nuclear matter size dependence of mass modification are measured

Momentum dependence

Expected

Measured by E325

$\Delta M \sim 35$ MeV
J-PARC E16 experiment

• confirm the E325 results, and provide new information
  – check the interpretation model: explain the data for many nuclei, many velocity bins.
  – momentum dependence is compared with the QCD prediction.
  – 'mass shift' of $\phi$ is connected to the s-quark condensate in finite-density medium.

Precedent exp. (KEK-PS E325)

$\phi$ (1020)
Cu
$\beta\gamma < 1.25$

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

Proposed exp. E16

Cu
Pb

Nuclear matter size dependence of mass modification are measured

Momentum dependence

Measured by E325
$\Delta M \sim 35 \text{MeV}$

Expected
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 ($12 \rightarrow 30/50 \text{ GeV}$): $x \sim 2$ of production
  - Higher intensity beam ($10^9 \rightarrow 10^{10} \text{ /spill (1sec)}$): $x \times 10$ ($\rightarrow 10\text{MHz}$ 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
High-p line in the Hadron hall
High-p line in the Hadron hall

- budget requested by KEK to MEXT: finally funded
  - thanks to KEK staffs
Beam test results of prototype detectors (2012)

GEM Tracker

HBD (Hadron-Blind Cherenkov detector)

Required position resolution (~100μm) is achieved

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

- Large size (300x300mm) PI- and LCP-GEM are successfully worked for a electron beam
  - Stability and response for a pion beam should be checked at J-PARC.
- GEM Tracker is successfully worked.
- Improvement of the photo-detection efficiency of HBD is on going.
**prototype to mass-production type**

**GEM Tracker**

**HBD** *(Hadron-Blind Cherenkov detector)*

- Large size (300x300mm) PI- and LCP-GEM are successfully worked for a electron beam
  - Stability for a pion beam is proved for the PI (50um) triple stack but LCP(100um) double stack
- GEM Tracker is successfully worked with a new preamp board.
- HBD optimization (gap size, pad size...) improves the pion-rejection factor.
Progress since 2012/1 (PAC-13)

- **R/O electronics** (Takahashi, Nakai, Kawama, Morino)
  - 1st version of preamp board for GEM detectors are tested w/ beam.
  - Trigger modules from Belle-II (UT3, FTSW) test are on-going.
  - LG-FEM prototype is delivered.
  - SRS modules for GEM readout are proved to have enough performance for the data transfer.

- **LG** (Aramaki, Sekimoto)
  - All LGs are decomposed.
  - A few samples are tested with beam successfully.

- **Spectrometer Magnet** (Muto, Ozawa)
  - Additional parts (yokes, poles and a coil) are delivered.
  - Pit is dug in the High-p experimental area, where the magnet should be located.
Progress since 2012/1 (PAC-13)

- **HBD (Aoki, Kanno)**
  - improvement of # p.e. and measurement of the pion rejection factor
  - use the PI-GEM triple stack instead of LCP double stack
  - new configuration of GEMs and R/O pads are tested.

- **GEM Tracker**
  - 1st mass-production type of 100mm is successfully tested w/ beam
  - trigger signal from the 3rd foil / ASIC is designed (Obara)
  - 1st version of the support frame is delivered (Shibukawa)
  - mass-production type of 200mm and 300mm are tested in Lab. (Komatsu)

- **GEM operation in the high-background environment (Kawama, Kanno)**
  - The 300mm PI-GEM triple stack with CF4 is operated without any breakdown in 15 hours in the AVF cyclotron room at RIKEN. Observed rate of the background neutron (and gamma-ray) are 100-1000 times as large as that expected in the High-p experimental area.
**GEM Tracker**

- **1st production type (100x100mm)**
  - trigger signal from the 3rd GEM foil
  - preamp board 1st version is used in the test

- **Support frame made by CFRP**
  - prototype is delivered in Mar.
GEM Tracker: first prod. type is tested

Y. Komatsu, to appear in NIM A

X-island for Y-strip (Ni plated)

X-strip 125µm (Ni plated)

Y-island

BVH type 2D R/O PCB
**HBD (Hadron Blind Detector)**

- Threshold type Gas Cherenkov, using CF$_4$
  - 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 t=100um double stack
  - CsI evaporation by Hamamatsu & RIKEN
  - QE improved at RIKEN
    - 10 photoelectrons detected (cf. PHENIX ~20 p.e.) as of 2011
- Test @ J-PARC in 2012: w/ pion beam
  - pion rejection factor measured for the first time
  - stability for the hadron-beam environment

managed by K. Aoki & K.Kanno
HBD (Hadron Blind Detector)

- Test @ J-PARC K1.1BR in 2012/Jun (T43)
  - #p.e. improvement: $10 \rightarrow 13$
    - QE, gas purity and HV config. optimization
    - however, still less than that of PHENIX (20 p.e.)

- 300mm LCP-GEM double stack was unstable in the hadron beam environment: breakdown in an hour

- Test @ J-PARC K1.1BR in 2013/Jan (T47)
  - 100mm/50mm PI-GEM triple stack were stable, even for CF$_4$
  - pion rejection is improved with a higher gain of new PI-GEM and smaller-size readout pad
    - measure the distributed charge
    - pion rejection factor 100 with e-efficiency 70% achieved, same level as PHENIX, in spite of the less #p.e.

- Test using 300mm PI-GEM in 2013/June: canceled
  - stability is checked at RIKEN

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HBD : New configuration

- gap length, gain, pad size...
  - PI-GEM (t=50um), triple stack
  - drift gap : 4mm to 1-2mm
  - 1<sup>st</sup> gap : 1.5 mm to 1 mm : to reduce the ionization by pion
  - 1<sup>st</sup> gap gain : 20 to 40 : to enhance the p.e. signal
  - readout pad size : a=16mm → 10mm
  - then we can expect
    - pion rejection 40 or more at 80% electron efficiency at online
    - pion rejection 400 or more at 70% electron efficiency at offline.

- required performance is almost achieved
  - move to mass-production in this year

managed by K. Aoki & K.Kanno
Schedule

• 2007: stage 1 approval
• 2008-2011: detector R&D
• JFY2012:
  – Test exp (T43/T47) at J-PARC
    • GEM stability and HBD response for pion beam
    • GEM R/O electronics
• 2013 Jan: High-p construction budget is approved
• 2013 Sep: start the mass production (GEM, tracker R/O board, etc.)
• In the Hadron hall schedule table, we are assigned
  – 2015 Feb-Aug: detector installation in the magnet
  – 2016 Jan-Mar: detector commissioning w/ beam
Summary

- Investigation of the hadron spectral modification in the nuclear matter is a study of the nature of QCD vacuum and its excitation.
  
  • 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 the hot (HI collisions) and dense (nuclei) matter in the dilepton invariant mass spectra.
  
  • modification of narrow resonances are only observed by KEK-PS E325.
  
  • 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 E325 and provide more precise information of the mass modification to clarify the chiral symmetry in the finite density matter.
  
  • preparation is underway with the Grant-in-Aid on Innovative Areas (“New hadrons”). Detector mass-production is just started.
  
  • Staged Goal of construction : 8 modules out of 26, by Jan 2016.
  
  • TDR will be prepared by the next PAC to obtain the stage-2 approval.
Backup slides...
Readout electronics

- APV25 chip and SRS are used for GEM readout
  - collaborating with CERN RD51

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GEM
- Tracker
- HBD
- Gas Cherenkov

E16 APV25-hybrid
- SRS APV25-hybrid
- TRG-ASF

~95000 ch (GTR 56000 + HBD 39000)

~1600 ch

CERN RD51 SRS
- DTC-LINK
- SRS ADC+FEC
- SRS CTX
- SRS SRU

TRG-MRG

Belle2 FTSW

Belle2 UT-3

Network switch

DAQ PC

Data flow
- Trigger primitive
- Global clock, global trigger

~1100 ch

Leadglass
- EMCAL
- 3" PMT

LG-FEM
- DRS4 + FADC```
HBD (Hadron Blind Detector)

- Test @ J-PARC K1.1BR in 2013/Jan (T47)
  - pion rejection is improved with a higher gain of new PI-GEM and smaller-size readout pad
    - measure the distributed charge: selecting 3 fired pads or more
  - pion rejection factor 100 with e-efficiency 70% achieved, same level as PHENIX, in spite of the less #p.e.

w/ and w/o cluster size analysis

![Graph showing pion rejection and e-efficiency results](image)

- Survival fraction of pions
- Charge threshold (e)
- Electron detection efficiency
- Rejection > 100
- E-eff. 70%
Lead Glass from TOPAZ / E362

17 frames were decomposed at KEK warehouse by Y. Aramaki & S. Sekimoto
Lead Glass

- **Online**
  - pion suppression down to 10% w/ the trigger threshold which keeps 90% of electron efficiency at 0.4GeV/c

- **Offline**
  - pion suppression down to 5% (2%) at 0.4(1.0) GeV/c w/ 90% electron efficiency
Spectrometer Magnet

FM magnet in the Hadron Hall
delivered in 2012
(managed by R. Muto)

additional pole pieces
coil
additional yoke
Detector R&D

- **GEM Tracker** to cope with the high rate
  - $\text{Ar} + \text{CO}_2(70:30)$
  - 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, CF$_4$ gas purity, etc.

- **Domestic Large size** (300mm x 300mm) GEM
  - kapton (Polyimide, PI) $t=50\,\text{um}$ for GT
  - LCP, $t=100\,\text{um}$ for HBD
**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
  - takes 6-8 months
    - scheduling of the area and overhead crane usage