有限密度媒質中でのクォーク相関の解明に向けたレプトン対精密測定

関連する計画研究: **A01**

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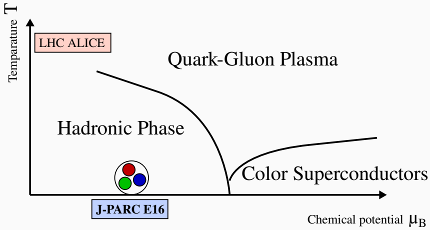
量子クラスターで読み解く物質の階層構造 **2021**年**6**月**14,19**日

Outline

- Introduction
- J-PARC E16 experiment
- Upgrade for E16 Run-1 (JFY2022) and byproduct measurement
- Research plan

Study of QCD phases with dilepton measurement



- High temperature $\longrightarrow$ LHC-ALICE (A01)
- Cold, finite density $\longrightarrow$ target of this research

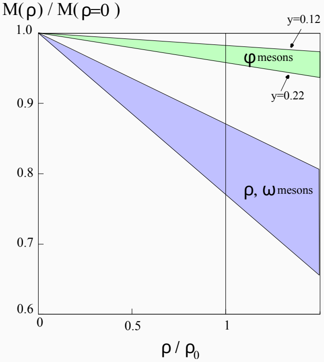
Finite density system

- What is the origin of hadron mass?
- Can we observe a signal of high density matter?

- Dilepton is good probe to study the properties of QCD
- Smaller final state interaction

Motivation 1: Origin of hadron mass

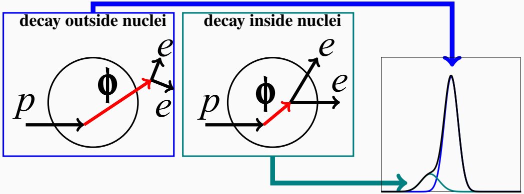
- Spontaneous chiral symmetry breaking is considered as the origin of hadron mass.
  - In hadronic phase, $\langle \bar{q}q \rangle \neq 0$
- In hot and/or dense matter, chiral symmetry is predicted to be restored.
- Amount of quark condensates depends on the restoration of the symmetry.
- Partial restoration of chiral symmetry in a finite density (nucleus) is expected to appear in changes of the mass spectrum.
- Vector meson is good probe for medium modification.

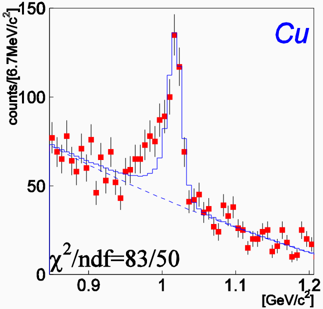


T. Hatsuda and S.H. Lee, PRC46 (1992) R34

ϕ meson mass spectrum

- KEKPS-E325: 12 GeV $p + A \to \phi + X$, $\phi \to e^+e^-$
- Clear excess is seen for slowly moving ϕ on Copper target.
- $\Delta M = -3.4^{+0.6}_{-0.7}\%$





R. Muto *et al.*, PRL98 (2007) 042501

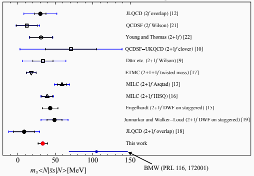
→ further study in J-PARC E16 with:

- High statistics: $\times 100$ of KEK-PS E325
- Better mass resolution: ~ 5 MeV

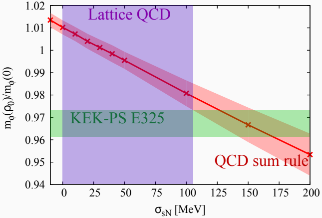
Systematic study on spectral change of vector mesons in nuclear medium

- $p + A \to \rho/\omega/\phi + X,\ \rho/\omega/\phi \to e^+e^-$
- Dependence on target nucleus size and momentum

Taken from M. Gong et al., PRD 88,014503

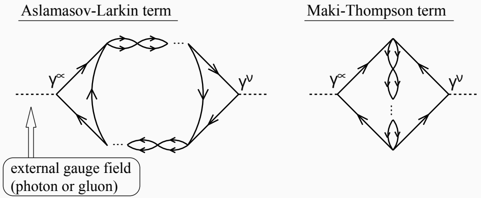


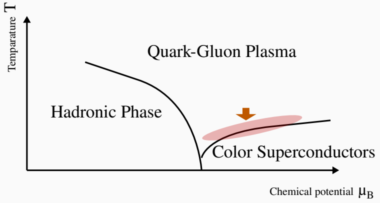
- ϕ msss in medeium is sensitive to $\langle \bar{s}s \rangle$
  - $\langle \bar{s}s \rangle_\rho = \langle \bar{s}s \rangle_0 + \langle N|\bar{s}s|N \rangle_\rho$
  - strangeness content in a nucleon: $\sigma_{sN} = m_s \langle N|\bar{s}s|N \rangle$
- QCD sum rule result: P. Gubler and K. Ohtani, PRD90, 094002
- E16 will give a strict constraint on the strangeness content in a nucleon.

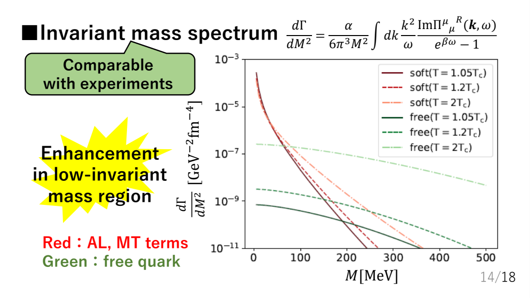


Motivation 2: Precursory phenomenon of high density matter

- Self-energy ($\Pi_{\mu\nu}$) of photon or gluon can be modified due to fluctuations of diquark pair-field
- Enhancement of invariant mass ($\frac{d\Gamma}{dM^2}$) near the critical temperature
  - T. Kunihiro, M. Kiazawa, Y. Nemoto, PoS CPOD07 (2007) 041; arXiv:0711.4429
  - M. Kitazawa JPS 2019 Fall presentation
  - T. Nishimura CPOD2021 presentation



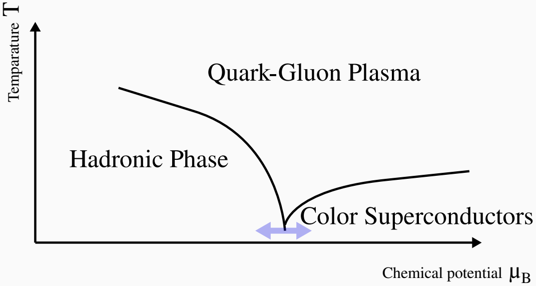




Taken from T. Nishimura CPOD2021 presentation

Detection of a precursory signal

- The discussion of the previous slide is valid near critical region. Far from normal nuclear density.
- Hadron-quark crossover
  - T. Schaefer, F. Wilczek, PRL 82, 3956
  - N. Yamamoto, M. Tachibana, T. Hatsuda, G. Baym, PRL97, 122001; PRL76, 074001



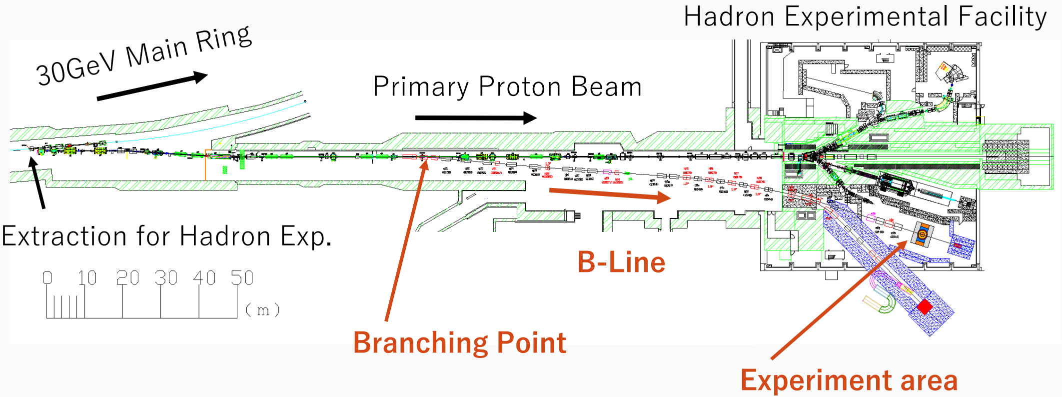
Experimetal challenges

- Measure e^+e^- invariant mass for various nuclear targets and compare them
- Background rejection: Dalitz decay
- Bin-by-bin analysis with respect to momentum
- Need high statistics

Experiment

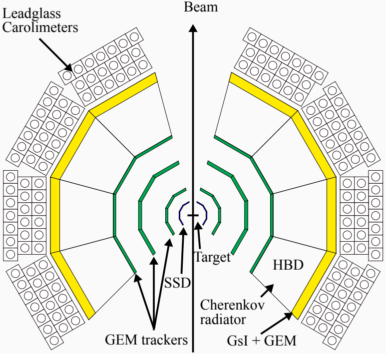
J-PARC High-momentum beam line

- 30 GeV, 10^{10} protons per pulse (2.06 sec in 5.2 sec cycle)

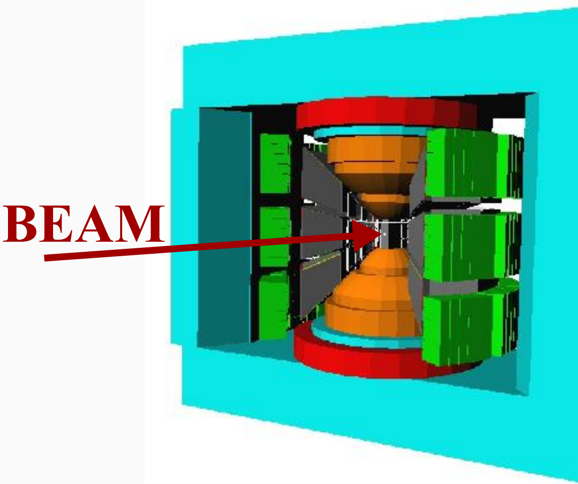


J-PARC E16 spectrometer

- Interaction rate: 10^7 Hz
- Tracker: SSD (Silicon Strip), GTR (GEM)
  - Mass resolution < 10 MeV/c^2
- eID: HBD (Cherenklov, GEM), LG (Calorimeter)
  - π rejection < 10^{-3}



~1.7 T at center



Staging strategy

Run-0 : 320 hours, C/Cu targets

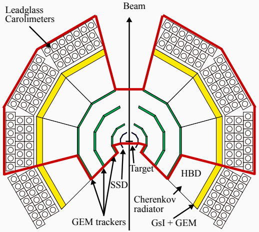
- Beamline & detector commissioning
- Meson yield
- Beam time completed! (Jun. 2020, Feb. 2021, Jun. 2021)

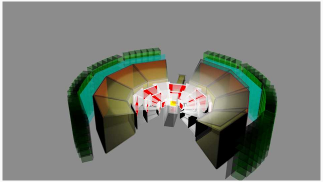
Run-1 : 1280 hours, C/Cu targets (physics run)

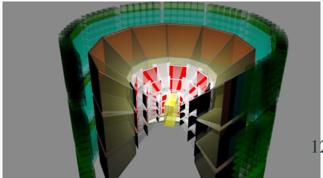
- JFY 2022
- 15k ϕ mesons collected
- Statistics: $\times 6$ of E325

Run-2 : 2560 hours, C/CH$_2$/Cu/Pb targets (physics run)

- Systematic study with various targets and high statistics







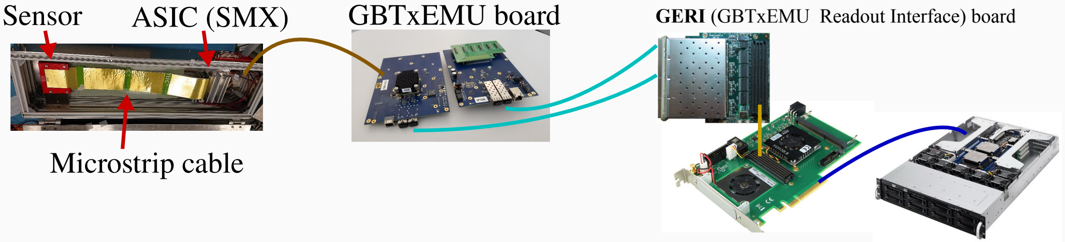
Upgrade of readout electronics

- **Trigger rate capability**
  - Readout of APV25, frontend chips of the readout of SSD and GTR, is a performance bottleneck.
  - Ancient VME readout system for SSD
    $\rightarrow$ **Replace with a new frontend chip.**
  - Many number of samples for GTR. With improvement including firmware upgrade and drift velocity optimization, upto a few tens kHz
- **No acceptance for low mass region below 100 MeV**
  - Main physics trigger of E16 requires a large opening angle to catch e^+e^- from ϕ.
  - On the other hand, e^+e^- pairs with the invariant mass below 100 MeV have a small opening angle.
    $\rightarrow$ **Use trigger-less readout electronics**

Upgrade 1 : SSD and its readout in E16 Run-1

Replace to GSI-FAIR CBM's sensor and electronics

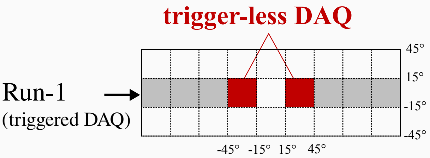
- Sensor: 80 μm pitch, single sided $\rightarrow$ 50 μm pitch, double sided
- Readout: APV25 (analog waveform) $\rightarrow$ SMX (peak ADC and TDC)
- SMX has trigger-less readout capability (max. 47M hits/s per chip), however, will be used in triggered DAQ of E16 Run-1
- NOTE: SSD upgrade is independent of this research.

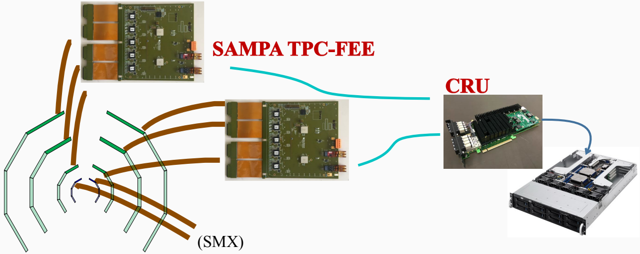


Upgrade 2 : GTR readout system for the measurement below 100 MeV

Continuous readout of forwarrd GTR with SAMPA + CRU (ALICE TPC FEE)

- Original Run-1: 8 modules in the middle part.
- Forward 2 modules will be read with the trigger-less system
- But still possibility of SMX (+ DSSD or GTR) instead of GTR+SAMPA





Research plan

JFY 2021

- Construct a testbench for SAMPA + CRU
- Readout test
- Integration of new FEEs and existing clock/trigger distribution system
- Study of data processing and analysis method

JFY 2022

- Installation of new FEEs and extra detector modules for the byproduct experiment
- Run-1 beam time and data taking
- Data analysis

Summary

- This research aims to study the QCD properties in a finite density through the measurement of the dilepton spectrum:
  - Spectral change of ϕ meson in nuclei $\rightarrow \langle \bar{s}s \rangle_\rho$
  - Prominent enhancement below 100 MeV $\rightarrow$ diquark condensate
- The measurement will be performed in JFY2022 beam time of J-PARC E16 Run-1.
- The trigger-less readout will enable us to measure the low mass region of the dilepton spectrum, which could provide a precursory signal of the high density matter, or reference measurements for future heavy ion collision experiments.