Report from high momentum beam line workshops

K. Ozawa

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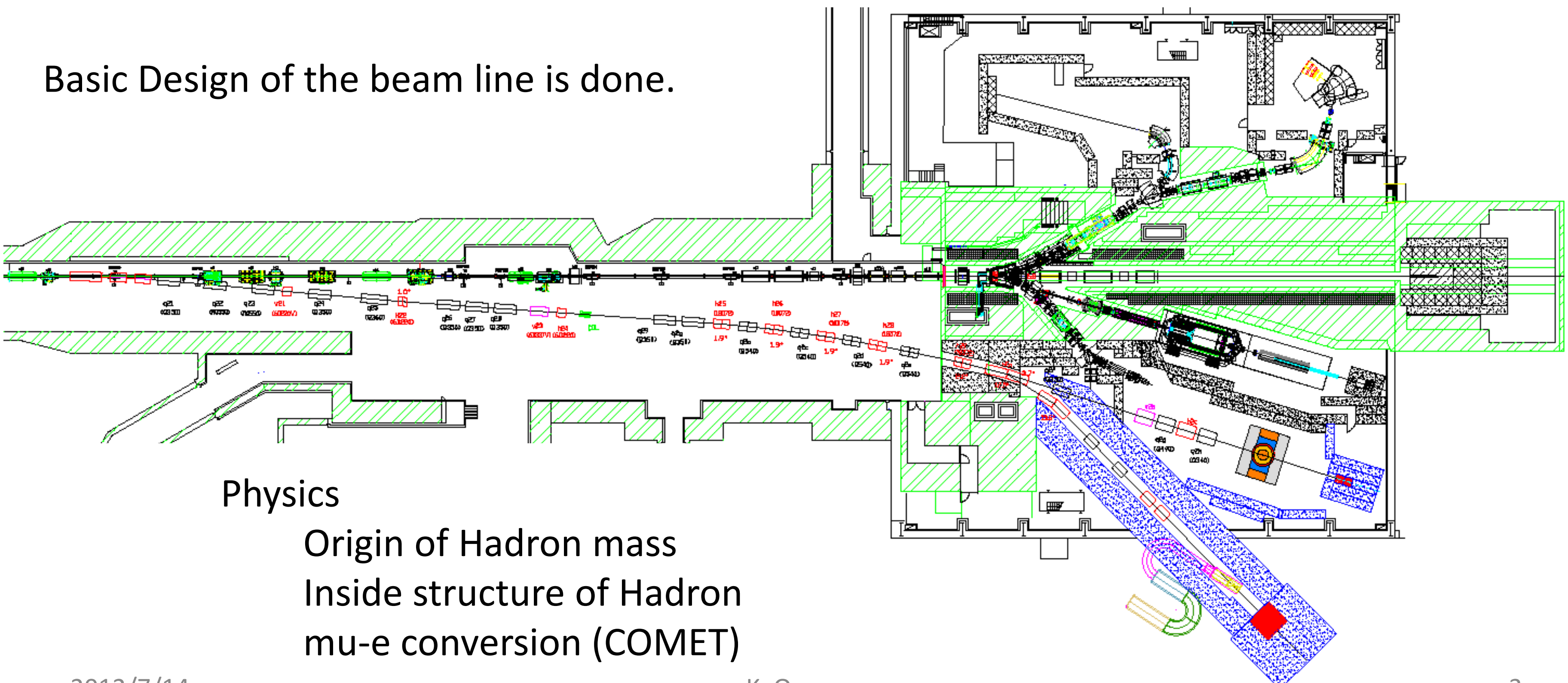
New High Momentum Beam Line

Construction of New Beam Line is proposed as a high priority plan of the lab.
Characteristics of the beam line is following.

- Primary Proton Beam (30GeV), $10^{10\text{-}12}$ per spill
- High Momentum un-separated secondary beam (< 15GeV/*c*), 10^7 per spill
- Primary Proton Beam (8GeV) for COMET

Basic Design of the beam line is done.



Physics

- Origin of Hadron mass
- Inside structure of Hadron
- mu-e conversion (COMET)

Activities

- High-p secondary beam physics collaboration
  - Led by RCNP (Research Center for Nuclear Physics, Osaka University), monthly meeting
  - Detailed Review by Project PAC of RCNP
  - Standing Technical Advisory Committee for the collaboration
- Di-lepton spectrometer collaboration
  - KEK, RIKEN, Academia Sinica, University of Illinois
  - Electron pair spectrometer for E16 experiment, monthly meeting
  - Mini-workshop in August for physics with Drell-Yan process
- Construction meeting
  - Weekly meeting to discuss several issues for a beam line construction.
  - Including COMET beam line

- Other related meetings / talks
  - Two workshops held by J-PARC theory center at Tokai in June and Dec.
  - KPS meeting/JPS meeting / Seminar at Kochi University
  - New hadron Spectroscopies Dynamics in Korea / Few Body
- International Workshop in the next week
  - Hadron physics with high-momentum hadron beams at J-PARC in 2013 January 15 - 18, 2013, KEK, Tsukuba, Japan http://www-conf.kek.jp/hadron1/j-parc-hm-2013/

Status

- One proposal has been submitted to this PAC meeting.
  - P50 - Charmed Baryon Spectroscopy via the (π, D^{*-}) reactions
- Several experiments are already under considerations.
- Further physics opportunities will be discussed at an internal workshop in the next week.
- Preparations of the beam line and the first experiment(E16) are in good shape.

- Your (practical) comments are very helpful, especially for
  - Extension of such activities to international communities
  - Enhancement of Physics opportunities
  - Suitable Detector techniques

Physics @ high-p

- **Hadron spectrum**
  - Puzzles in hadron physics
    - States cannot be easily explained in simple manners
    - Unexpected states
  - **Internal structure of hadron** should be investigated.
    - Charmed baryon spectroscopy can provide essential information.
    - In addition, basic information, such as a form factor, is important.
- **Hadrons in nucleus**
  - Hadron mass is dynamically generated and strongly related with medium properties.
  - **Experimental information in different medium,** such as nucleus as finite density matter, are important to know how mass is dynamically generated.

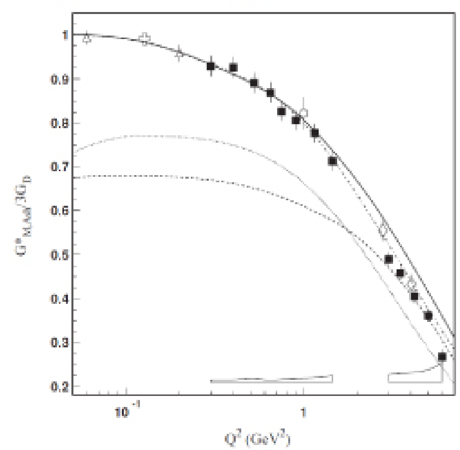
Internal structure of Hadron

- One of the powerful tools to study internal structures of hadrons is a measurement of form factor. There are very successful results for electromagnetic form factors.

- To establish a model of internal hadron structure, form factors of baryon resonances are important, since baryon resonances reflects excitation of internal interactions in hadrons and can provide information of internal interactions.

- Transition electromagnetic form factors of baryon resonances has been measured by $\pi/\pi\pi$ electro-production at J-Lab, intensively.

$G_M^*(Q^2)$ for $\gamma^* p \to \Delta$



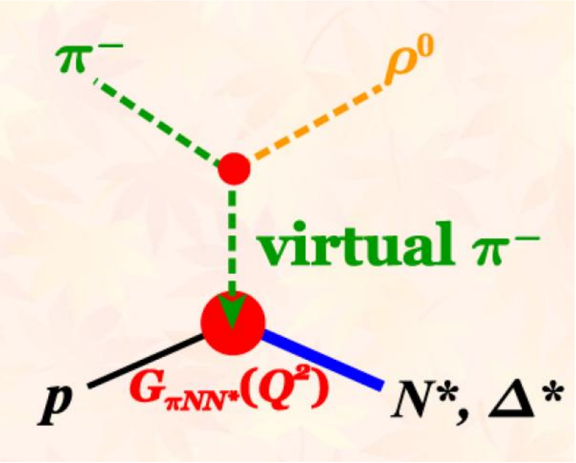
I.G. Aznauryan *et al.* (CLAS Collaboration), Physical Review C **80**, 055203 (2009).

Axial Form factor

- Axial form factor means a spatial distribution of components which couple to pseudo scalar meson (π, K,…) in hadron. Coupling to π meson is essential for hadron interaction and axial form factor provides direct information of hadron structure.

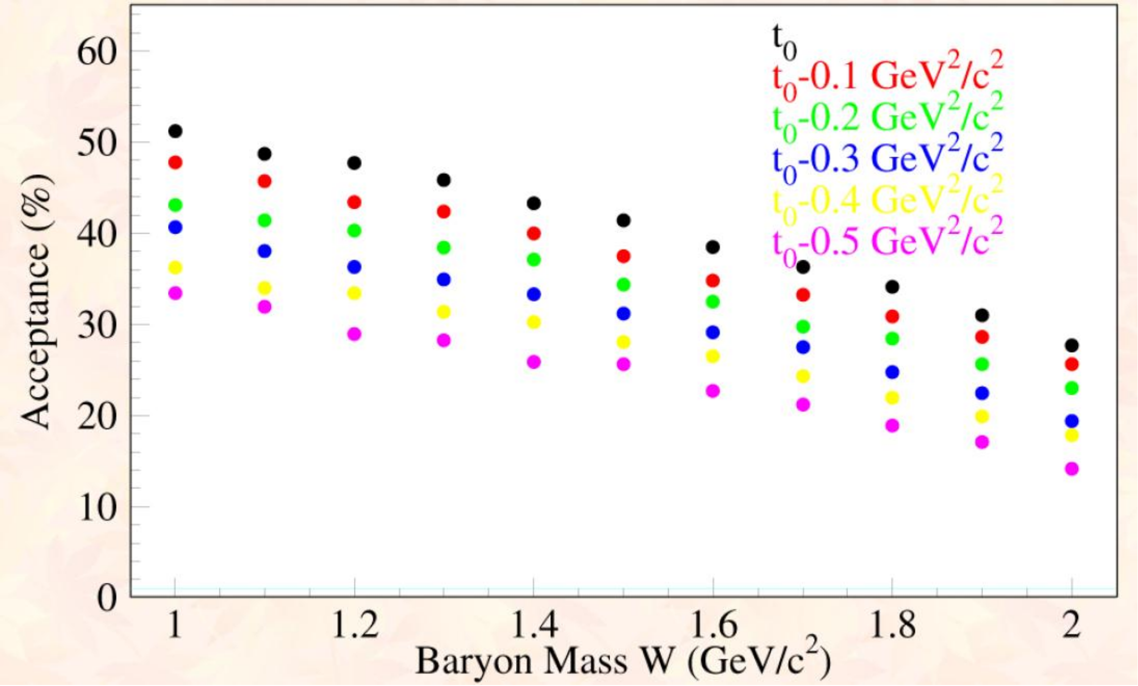
- Axial form factors of nucleon is measured by quasi-elastic νN scattering(νn'->μ^+p) and π^+ electro-production(ep->eπ^+n). However, there is almost no information for axial form factors of baryon resonances.

- Axial transition form factors from the nucleon to a baryon resonance can be measured using a forward vector meson production.
  - Forward vector meson production is t-channel dominant.
  - Partial Conserved Axial-vector Current (PCAC) method can link production cross sections and axial form factors.



Experiment

- Observable is a production cross section of vector meson as a function of t.
- Charmed baryon spectrometer will be used also for this experiment. There is enough acceptance. Missing mass resolution of 10 MeV/c^2 can be achieved.

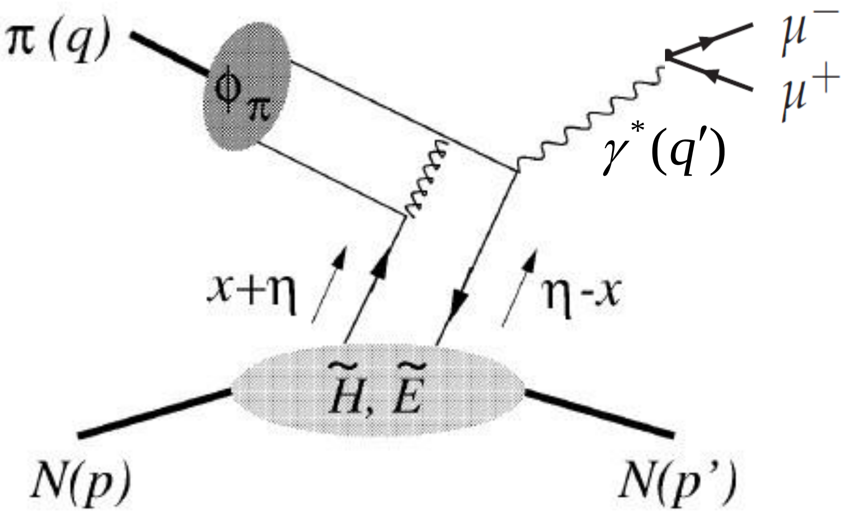


Measurements of K* production are also under discussions to investigate strange quark sector.

Generalized Parton Distributions

- Similar physics is discussed in a different context by Prof. Sawada (KEK) and his company.
  - Prof. W.C. Chang (Academia Sinica), Prof. J.C. Peng (University of Illinois), Prof. S. Kumano, and Dr. H. Kawamura (KEK)
- Exclusive lepton pair productions in πN scattering access Generalized Parton Distribution (GPD) and pion distribution amplitude.

E. Berger *et al*., PLB 523, 265 (For COMPASS)



ϕ_π: pion distribution amplitude
H, E: Generalized Parton Distributions

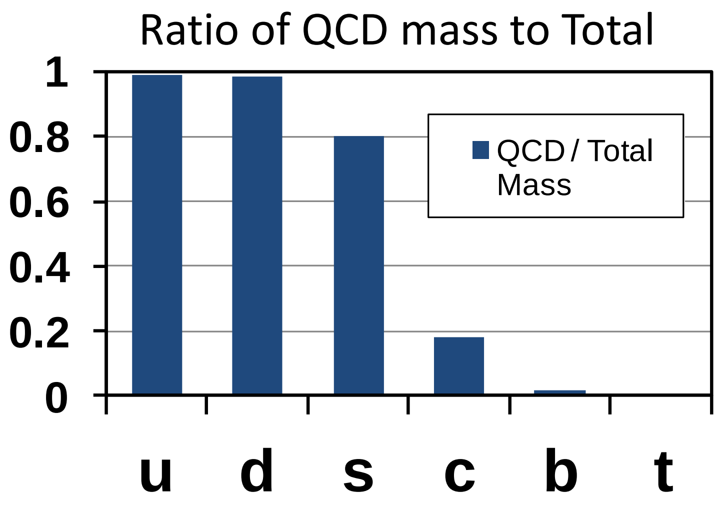
Using a Drell Yan process, spin-related decomposition can be done.
In the back ward production, the same measurement gives πN transition amplitude (B. Pire et al., PRD71 111501).

Large acceptance lepton pair spectrometer is required. Feasibility using the E16 spectrometer is under consideration.

Physics with Kaon

- Un-separated secondary beam contains 1-10% Kaons. If a smart trigger system to select kaon is adopted, kaon physics can be done using a high momentum beam.
- Physics examples under discussions,
  - Ξ_c Spectroscopy
    - Investigate Strangeness and Charm sector
    - $K^- + p \rightarrow \Xi_c + D^-$ (Production Threshold: 10 GeV/*c*)
    - Use the same spectrometer with charm baryon spectroscopy. Experimental issues, such as yield, background, resolutions, are being evaluated.
  - Charmed exotic baryons
    - Θ_{cs} can be searched using a similar reaction.
    - $K^- + p \rightarrow \Theta_{cs} + D^+$

Origin of hadron mass (E16)

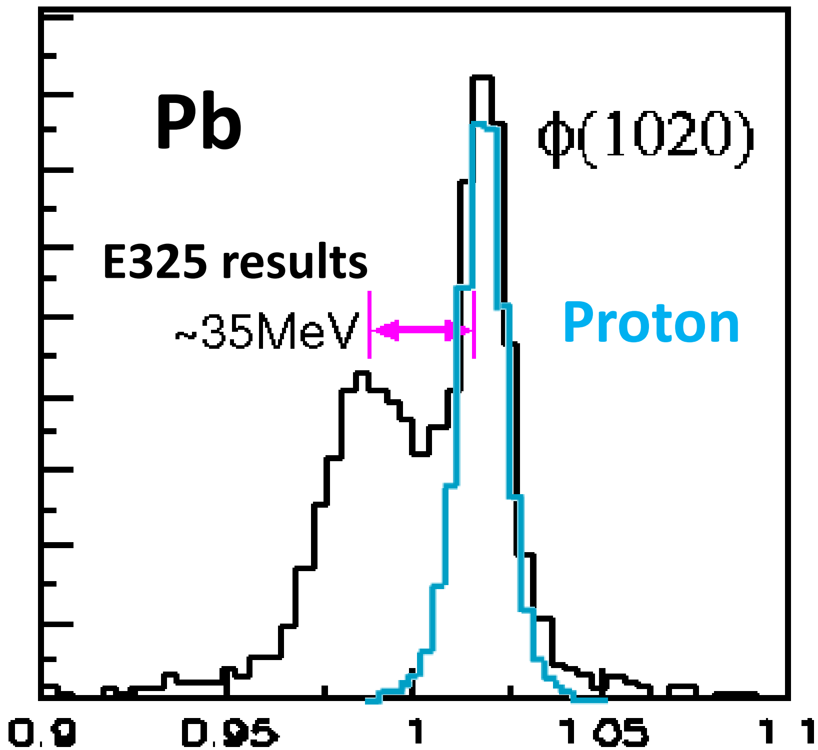


- In light quarks (u, d, s) sector, hadron mass consists of Bare mass (Higgs) and Dynamical mass (QCD).
- Dynamical mass part is strongly related to a surrounded medium and reliable experimental information in a different medium is important.

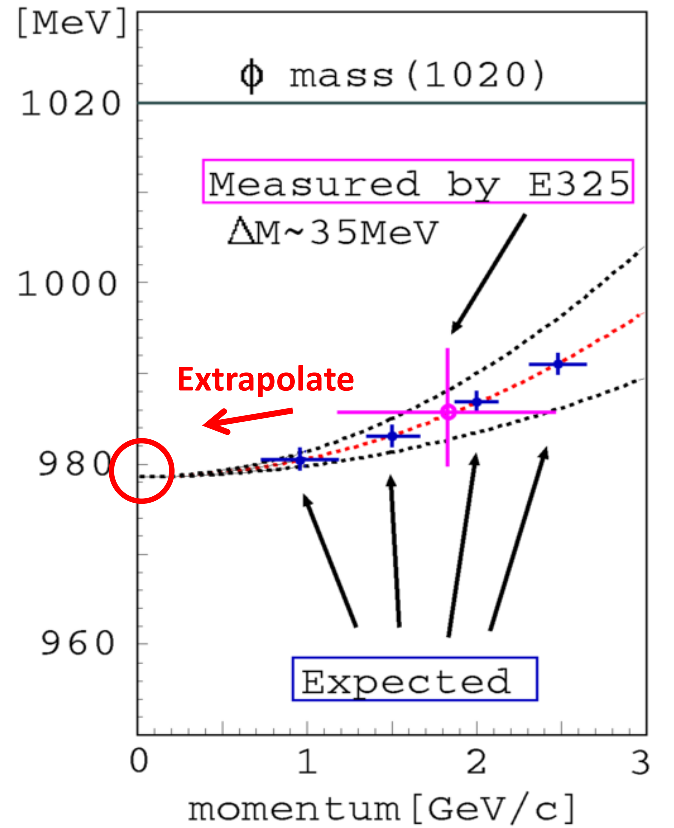
- **Establish QCD-originated effects in nucleus, experimentally.**
  - Provide experimental information for QCD mass in dense matter
- Vector mesons (ρ, ω, ϕ meson) are used as probes.
  - Mass spectra of vector mesons can connect to $\bar{q}q$ condensates
    - e.g. Hatsuda and Lee, PRC 46 (1992) R34
  - Use leptonic (electron) decays to avoid the final state interaction

Goal of the experiment

A clear shifted peak needs to be identified to establish QCD-originated effects



Momentum Dependence



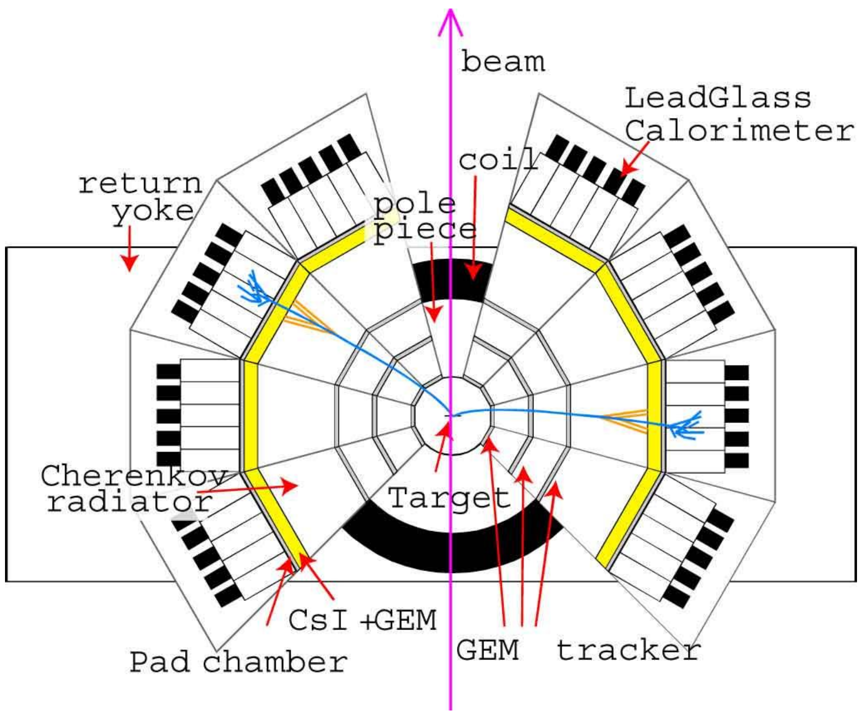
100 times larger statistics and two times better mass resolution will be achieved.

Electron Pair Spectrometer

Cope with 10^{10} per spill beam intensity

Extended acceptance (90° in vertical)

Gas Electron Multiplier (GEM) technology is fully adopted.



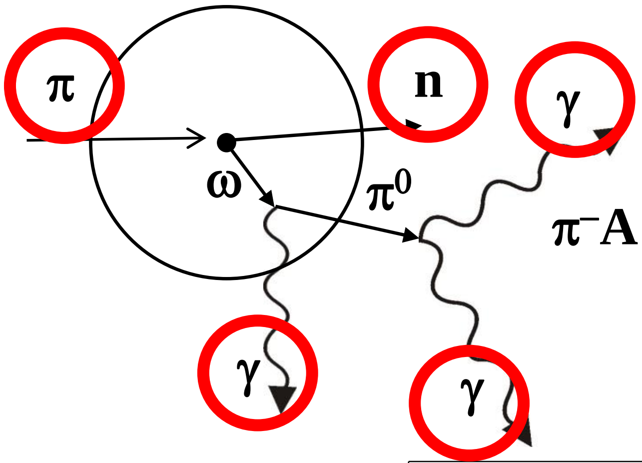
GEM Tracker

A realistic prototype including a readout system is tested at J-PARC (T47).
Required resolution (100μm) is achieved up to the incident angle of 30 degrees.
Remaining issue is effect of magnetic field.

Hadron Blind Detector (electron ID)

Number of photo-electrons of 15 is achieved and the characteristics of CsI photocathode and GEMs are understood by several measurements at a laboratory.
Hadron response is being measured (T47).

E26 @ high-p beam line

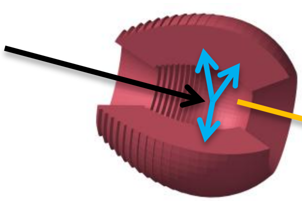


$$\pi^- A \rightarrow \omega + n + X$$
$$\omega \rightarrow \pi^0\gamma, \quad \pi^0 \rightarrow \gamma\gamma$$

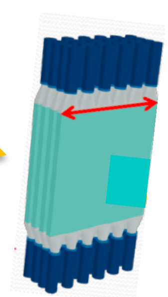
$$m_\omega = \sqrt{(p_\pi + p_\gamma)^2}$$

Measurements of ω meson mass spectrum
- Physics is similar with E16
- Production of ω is also measured
- Focus on low momentum ω meson
- Clear mass spectrum in nucleus

Beam Momentum is 2.0 GeV/c.
- Original plan uses K1.8 Beam line. High momentum beam line can be used.



γ detector around the target



Neutron counter at the forward direction

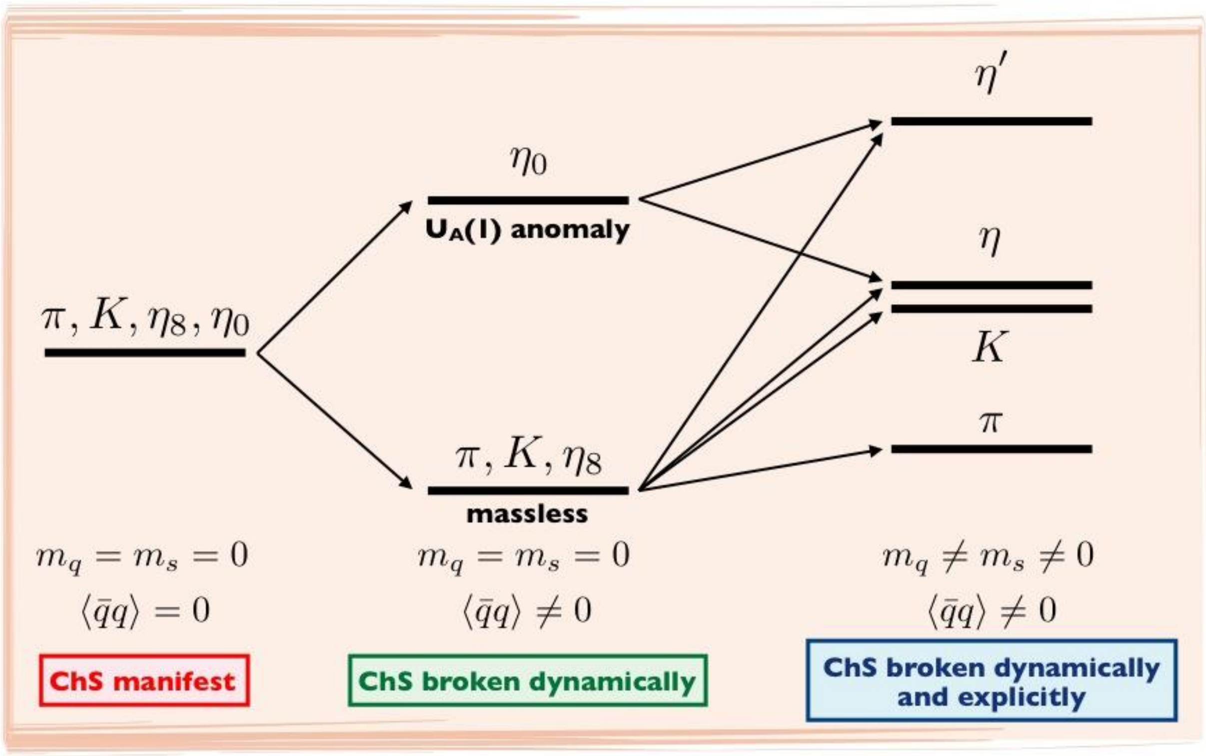
Compatible with Charm baryon spectrometer
- Arrangement around target is needed.

Neutron flight path can be increased.
- 7m -> 10m
- Missing mass resolution can be improved, though, acceptance is decreased.

Optimization of the experimental set up is underway.

Pseudo Scalar meson

Nagahiro et al., arXiv:1211.2506



- Pseudo Scalar meson can be considered as a NG boson in spontaneous breaking of chiral symmetry. Thus, study of pseudo scalar meson is important.

heavy η′ mass (958MeV) because of chiral symmetry breaking *and* $U_A(1)$ anomaly
Large mass reduction of η′ in medium is predicted. (Nagahiro et al., PRC 74, 045203 (2006))
Search for η′-mesic nuclei is proposed at several labs (GSI, LEPS2, FOPI, CBELSA)

Information of basic η′ – nucleon interaction is insufficient and should be studied at J-PARC.

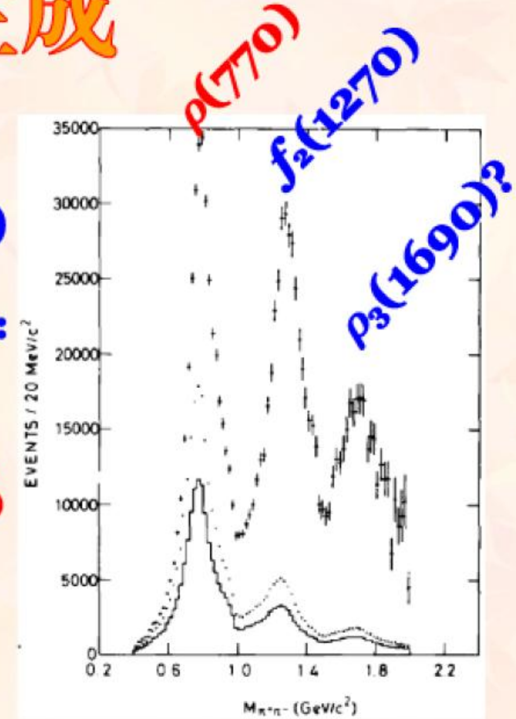
Summary & Outlook

- Several Physics opportunities and experiments are under discussions.
- One major topic is internal structure of hadron and form factors. Our experiments can provide unique information
- Another major topic is hadron properties in nucleus. Several interesting experiments are already proposed or being proposed.

- At this moment, we concentrate on enhancement of our physics program. Related physics and experiments are being performed at J-LAB, GSI, COMPASS, ELPH, LEPS, and so on. As the next step, we will find collaborations to maximize our physics outputs.

BACK UPS

超前方ベクターメソン生成

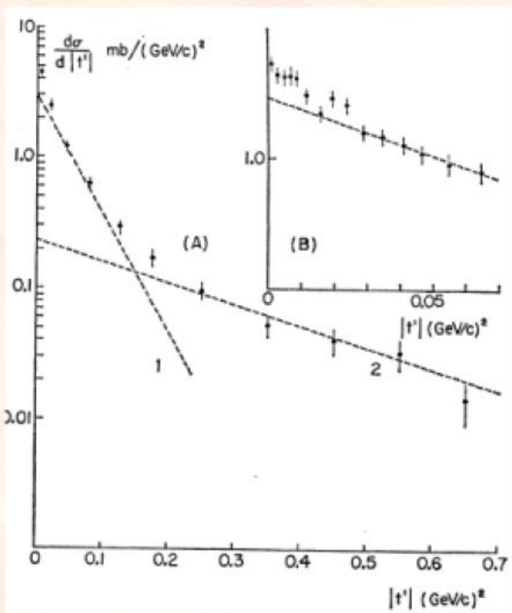


π^- ビーム (17 GeV/c)

$d\sigma/dt$=0.3 mb/GeV^2 ($M_{\pi\pi}$ 0.70-0.85 GeV)

G. Grayer *et al.*,
High statistics study of the reaction $\pi^- p \rightarrow \pi^+\pi^- n$: apparatus, method of analysis, and general features of results at 17 GeV/c,
Nucl. Phys. B75, 189 (1974).

ρ 生成が確認できる



π^+ ビーム (13.1 GeV/c)

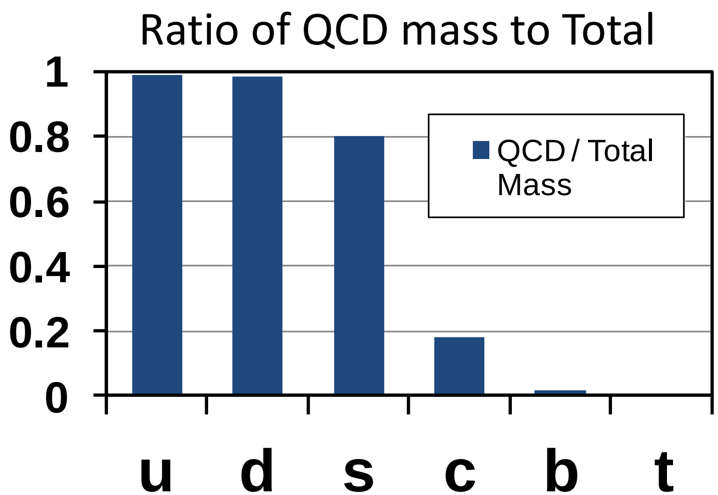
$d\sigma/dt$=4 mb/GeV^2

J.A. Gaidons *et al.*,
Reaction $\pi^+ p \rightarrow \rho^0 \Delta^{++}$ at 13.1 GeV/c,
Phys. Rev. D 1, 3190 (1970).

***t* チャンネル過程が支配的である**

T. Ishikawa, 29th November 2012.

E16: Origin of Hadron Mass



- In light quarks (u, d, s) sector, hadron mass consists of Bare mass (Higgs) and Dynamical mass (QCD).

- **Establish QCD-originated effects in nucleus, experimentally.**
  - Provide experimental information for QCD mass in dense matter
- Vector meson (ϕ meson) is used as a probe.
  - Mass spectra of vector mesons are sensitive probes to QCD mass.
    - e.g. Hatsuda and Lee, PRC 46 (1992) R34
  - Use leptonic decays to avoid the final state interaction

Which is the best, ρ/ω or ϕ?

- ρ/ω
  - Dynamical mass contribution is dominant
    $M_\pi \sim 130$ MeV/c^2 $M_\rho \sim 770$ MeV/c^2
  - Large hadronic effects and background issues are large
- ϕ
  - Still, dynamical mass contribution is dominant
    $M_\eta \sim 550$ MeV/c^2 $M_\phi \sim 1020$ MeV/c^2
  - Narrow width (4.3 MeV/c^2)
    - Small background issue
  - **Small effects of hadron-hadron interactions**
    - e.g. Binding energy of ϕN is 1.8 MeV (Phys. Rev. C 63(2001) 022201R)

To see QCD-originated effects, ϕ meson is the most promising probe.

Current status of experiments

Most measurements are done for ρ/ω mesons

- High energy heavy ion collisions
  - SPS-NA60 (PRL 96 (2006) 162302)
    - Modification of ρ meson due to hadronic effects
  - RHIC-PHENIX (PRC81(2010) 034911)
    - Origin of the enhancement is under discussion
- Nuclear targets
  - CBELSA/TAPS (Phys.Rev. C82 (2010) 035209)
    - Modification of ω is not observed
  - J-LAB CLAS G7 (PRL 99 (2007) 262302)
    - Mass broadening of ρ due to hadronic effects
  - KEK-PS E325 (PRL 96 (2006) 092301)
    - Peak shift and width broadening of ρ/ω

Large uncertainty in background subtraction method

Several hadronic and experimental effects cause difficulties in ρ/ω measurements.

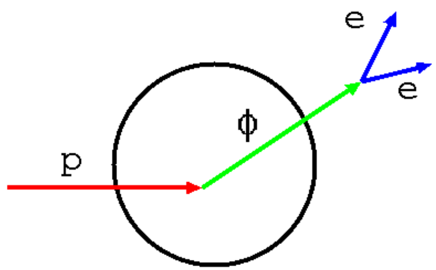
Clear measurements of φ meson at KEK-PS.

The only one measurement on medium modification of φ meson.

R. Muto et al., PRL 98(2007) 042581

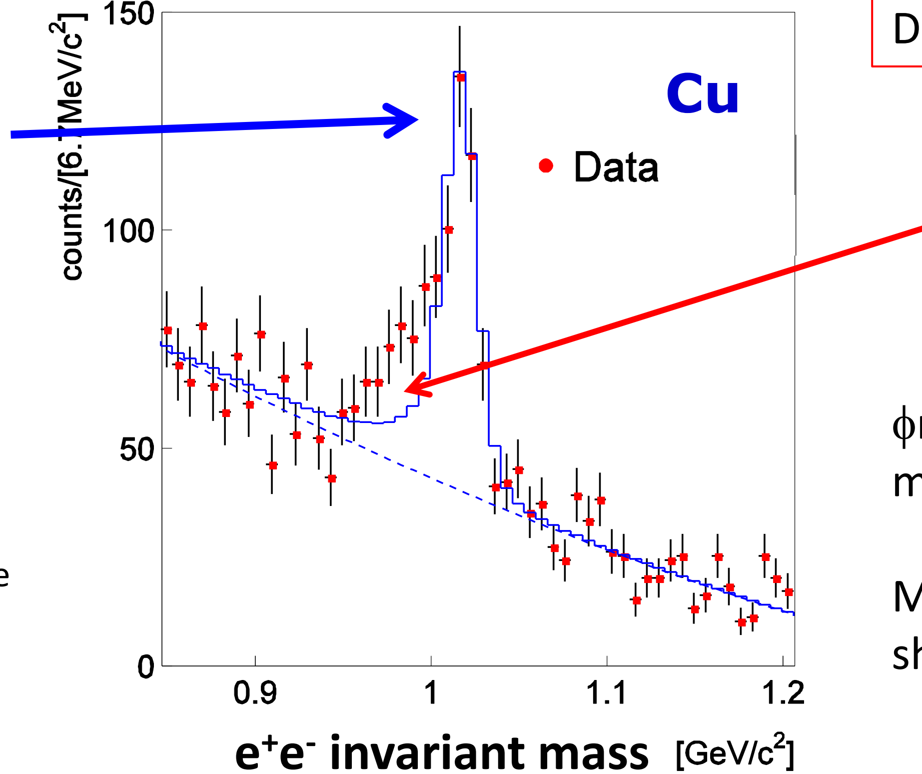
βγ<1.25 (Slow)

Decays **outside** nucleus

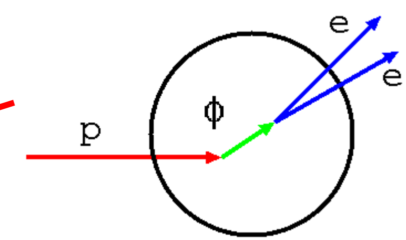


φmeson has NO mass modification

Blue line shows expected line shape including all experimental effects wo mass modification



Decays **inside** nucleus

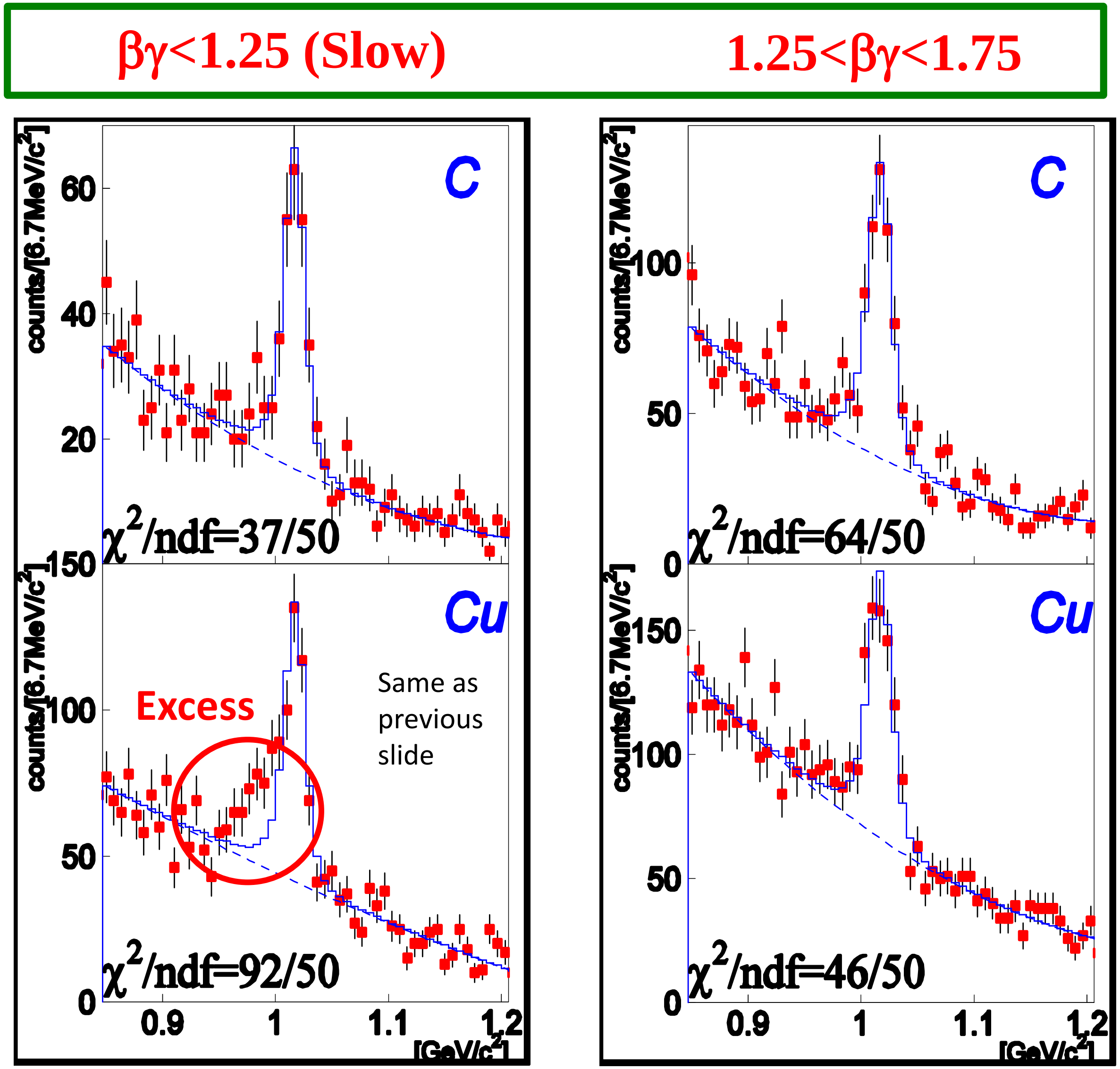


φmeson has mass modification

Modification is shown as an **Excess**

Indication of QCD-originated mass modification!

Target/Momentum dep.



e^+e^- invariant mass

Two nuclear targets:
- Carbon & Copper
- Inside-decay increases in **large nucleus**

Momentum bin
- **Slowly moving ϕ mesons** have larger chance to decay inside nucleus

Only one momentum bin shows a mass modification under the current statistics.

To see clear mass modification and establish QCD-originated effects, significantly larger statistics are required.

Requirements for beam and spectrometer

- To obtain 100 times larger statistics
  - High beam energy of 30 GeV (x2 statistics)
  - Beam intensity: 10^{10} per spill (x10)
  - Extended acceptance of the spectrometer (x5)

- Mass Resolution needs to be improved to ~ 5MeV/c^2
  - ΔM ~ 35 MeV/c^2, Γ ~ 15 MeV/c^2: E325 (~ 11 MeV/c^2)

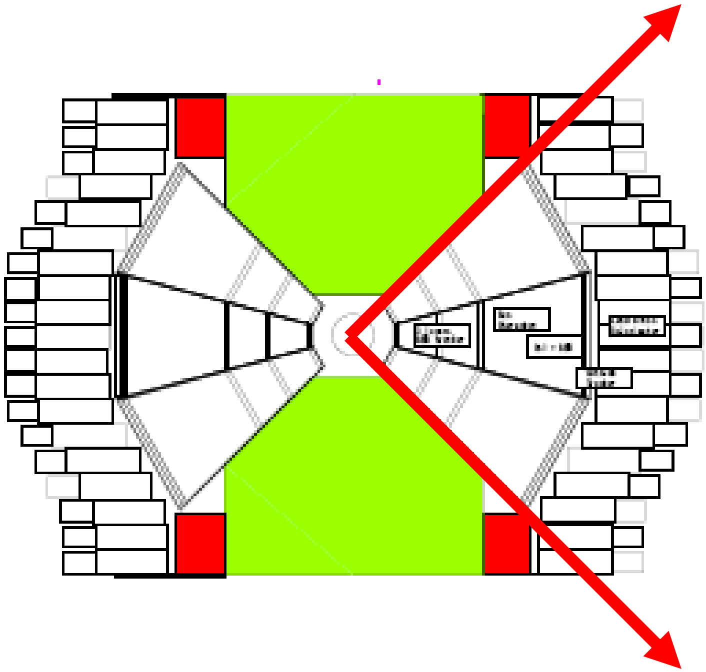
- Wider target mass range to have a clear modification
  - Proton and Lead targets

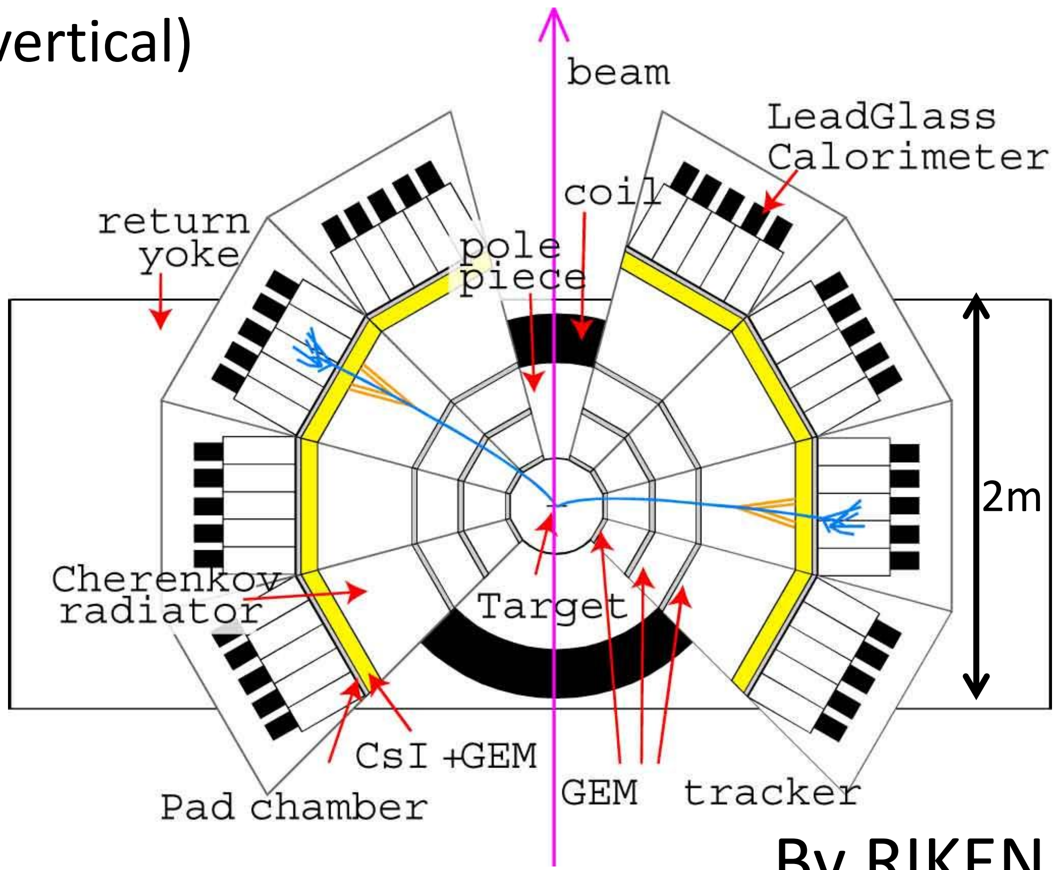
To satisfy above requirements, we need to construct a new beam line and totally new detectors.

Spectrometer

Cope with 10^{10} per spill beam intensity

Extended acceptance (90° in vertical)



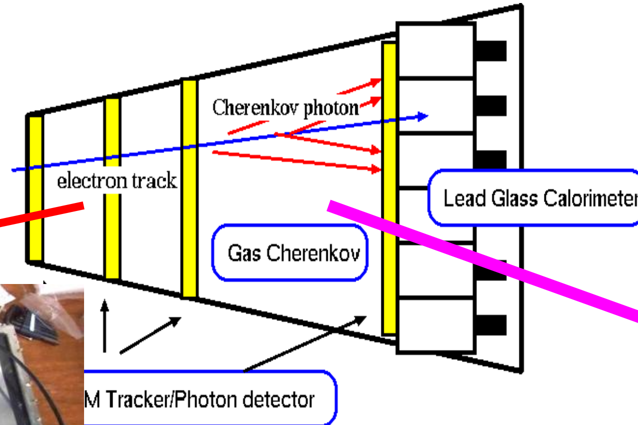


By RIKEN

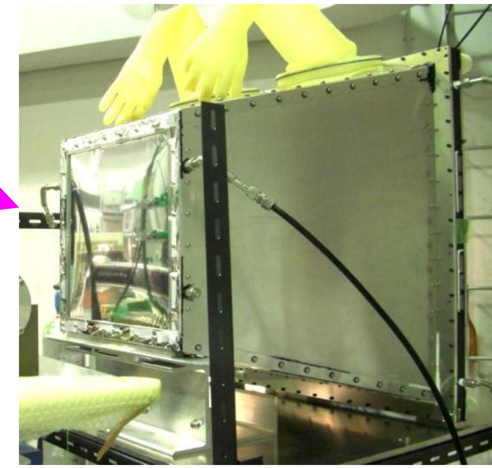
Gas Electron Multiplier (GEM) technology is fully adopted.

Detector components

GEM Tracker



HBD (Hadron-Blind Cherenkov detector)



100x100 200x200 300x300

Position resolution of 100μm is achieved

Key Technology:

CsI evaporated GEM as a photo cathode

Q.E. of 40% is achieved

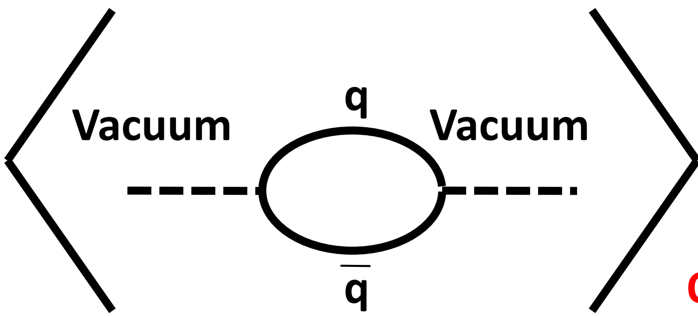
Concern about long term stability of CsI (Reply to PAC13 comments)

- We assume 1-2 month running per year and several years
  - PHENIX-HBD already prove the 6 month operation in Run-10 : accumulated life is same order
  - Re-evaporation of CsI is possible between our Runs for damaged one

Condensates and Spectrum

How to access quark condensate experimentally?

Unfortunately, quark condensates is not an observable.
We can link condensates and vector meson spectrum.

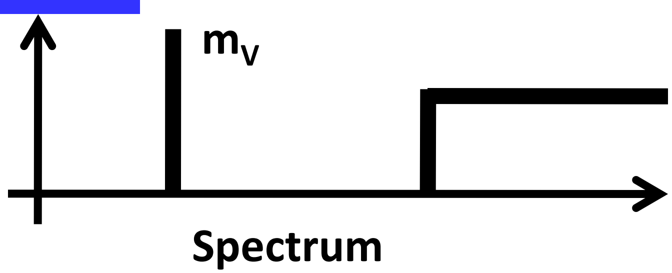


QCD sum rule

Average of Imaginary part of $\Pi(\omega^2)$
vector meson spectral function

The relation is established by Prof. Lee and Prof. Hatsuda.

Assume



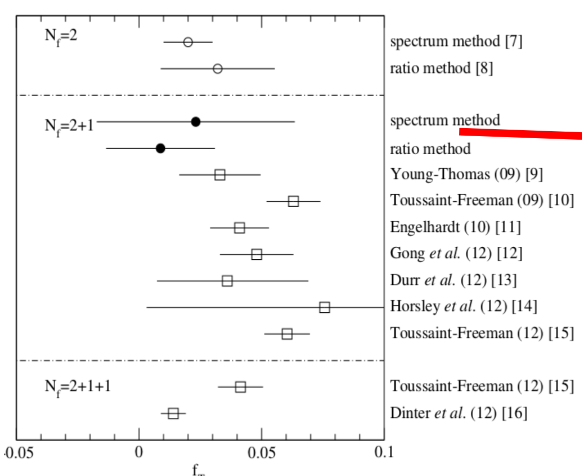
Prediction

T.Hatsuda and S. Lee, PRC 46 (1992) R34

$$\frac{m_V^*}{m_V} = \left(1 - \alpha \frac{\rho_B}{\rho_0}\right) \; ; \; \alpha \approx 0.03$$

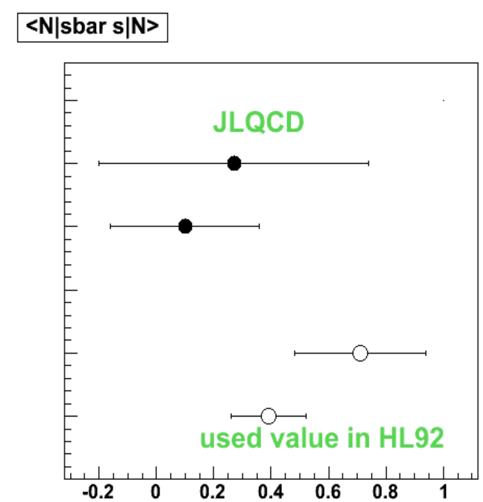
<ss> & ϕ-meson mass

- <ss>(ρ) (ss condensate in medium whose density is ρ) is relevant the ϕ mass in nuclear matter under the QCD sum rule analysis by Hatsuda & Lee (PRC46(92)R34 : HL92)
  - linear approx. : <ss>(ρ)=<sbar s> (vac) + <N|ss|N> x ρ
  - <N|ss|N> is evaluated using (old value of) y and π-N sigma term
- Recently <N|ss|N> (so called " strange quark content of the nucleon") is calculated with Lattice QCD
  - found to be smaller than the assumed value in HL92, however, agree within the error



$f_{Ts} = m_s/m_N$ <N|ss|N>

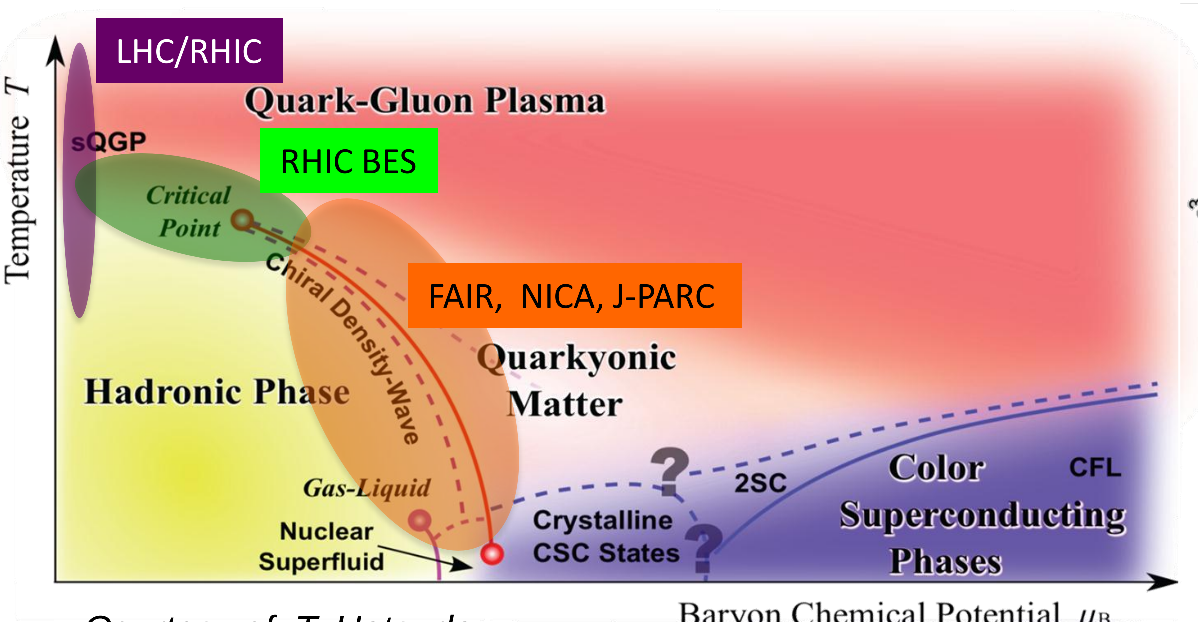
m_s=80MeV



arXiv:1208.4185

Heavy Ion Physics at J-PARC

- Physics interests:
  - Exploring the QCD phase diagram at high baryon density (ρ_B~5-7ρ_M)
    - Stragnelets, Quark matter, gas-liquid, color super-conductivity
    - (Onset of) Deconfinement phase transition at high ρ_B
    - (Onset of) Chiral symmetry restoration at high ρ_B
  - Medium Properties (EOS, eta/s, qhat) at high ρ_B
  - Multi-strange matter(double lambda hypernuclei, strange dibaryon)



Courtesy of T. Hatsuda