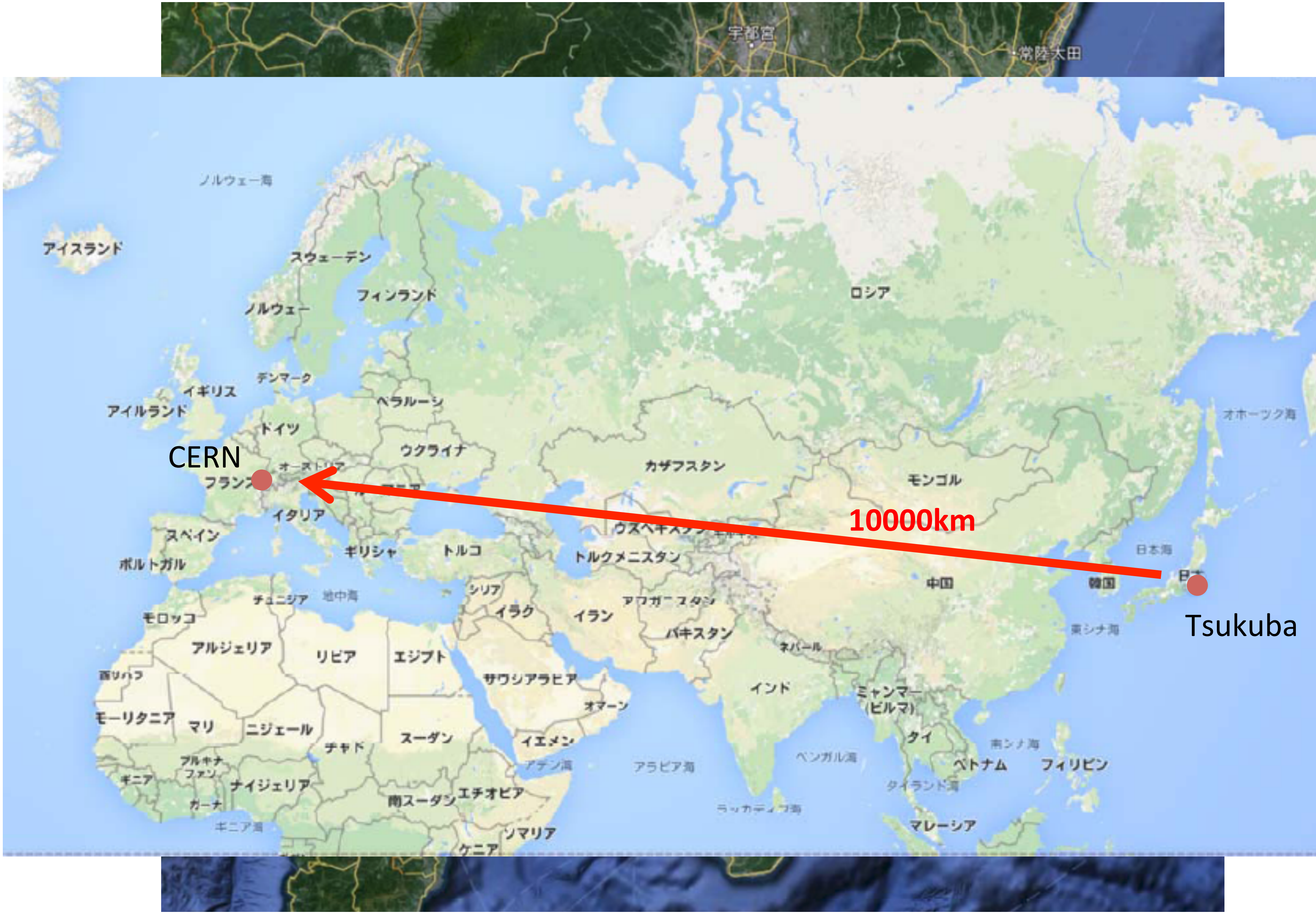
Low-mass di-leptons in J-PRAC E16

K. Ozawa (KEK)

Contents

- J-PARC and Hadron Experimental Facility
- Di-electron measurements @ J-PARC
  - Vector meson mass spectra in nucleus
- Further possibility in pA mesurements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10000km
宇都宮
常陸太田
ノルウェー海
アイスランド
スウェーデン
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ノルウェー
デンマーク
イギリス
アイルランド
ドイツ
ベラルーシ
ウクライナ
ロシア
カザフスタン
モンゴル
イタリア
スペイン
ポルトガル
ギリシャ
トルコ
トルクメニスタン
中国
韓国
日本海
オホーツク海
東シナ海
チュニジア
地中海
シリア
イラク
イラン
パキスタン
ネパール
インド
モロッコ
アルジェリア
リビア
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サウジアラビア
オマーン
モーリタニア
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アラビア海
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南スーダン
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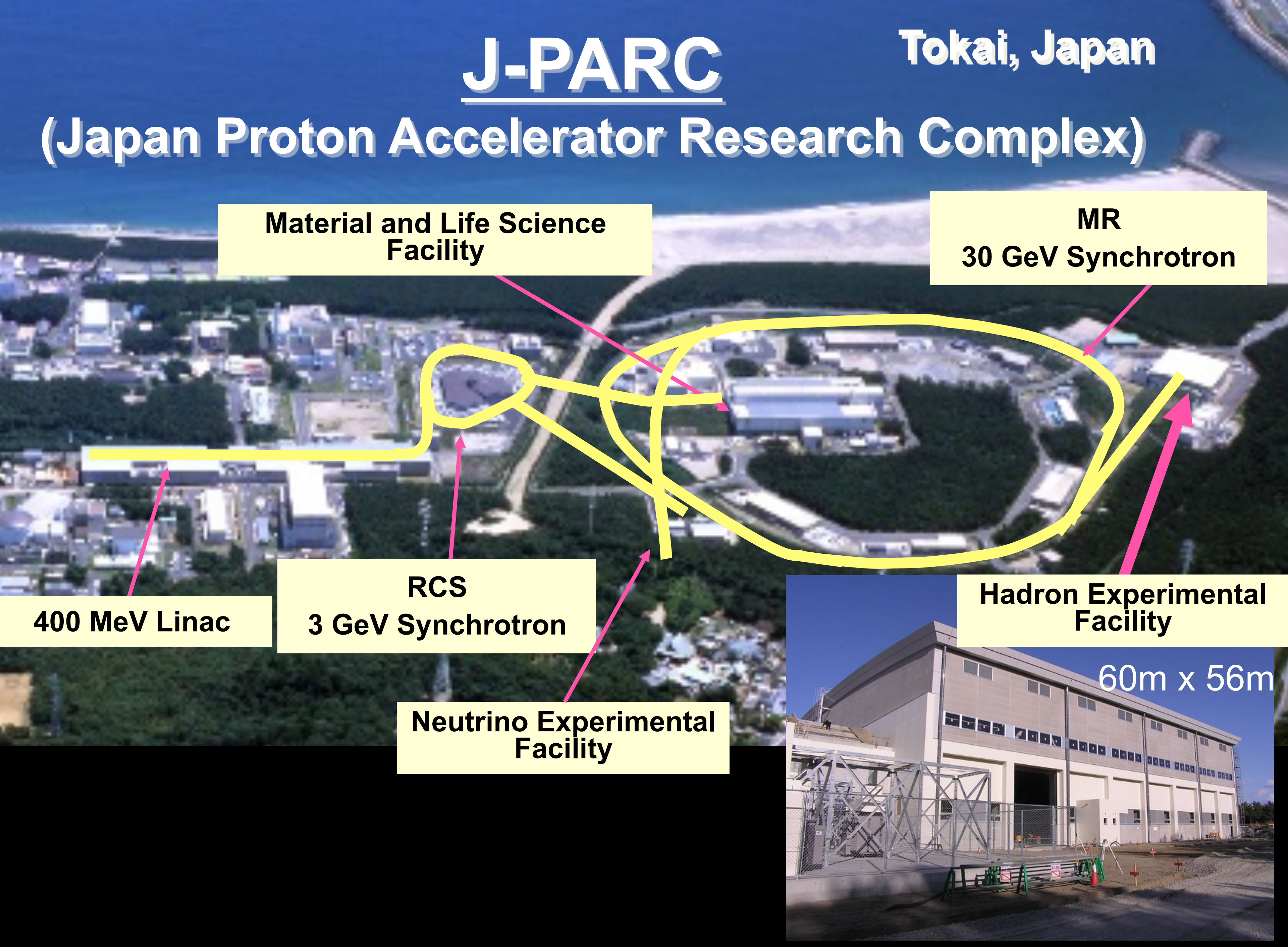
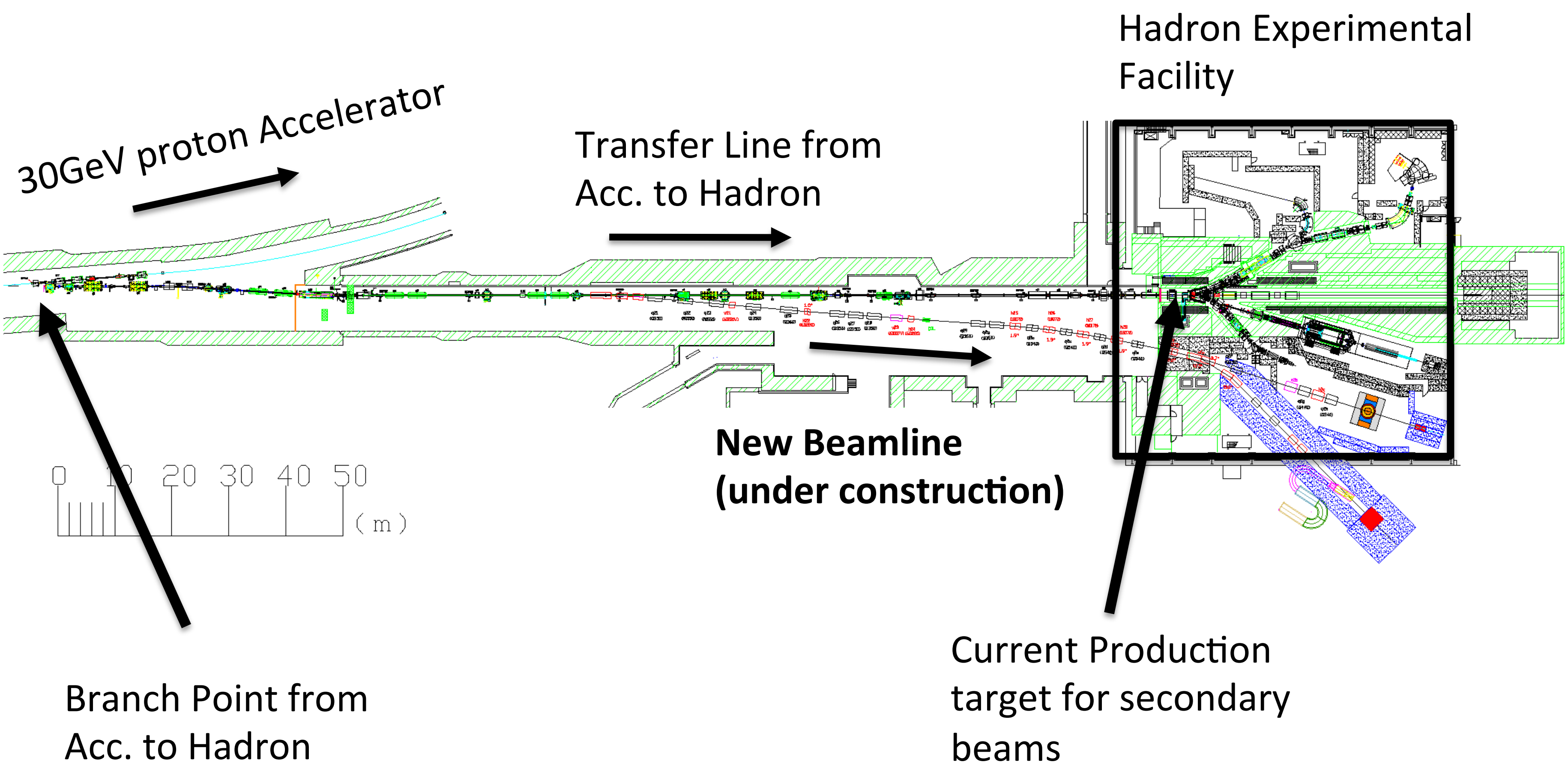
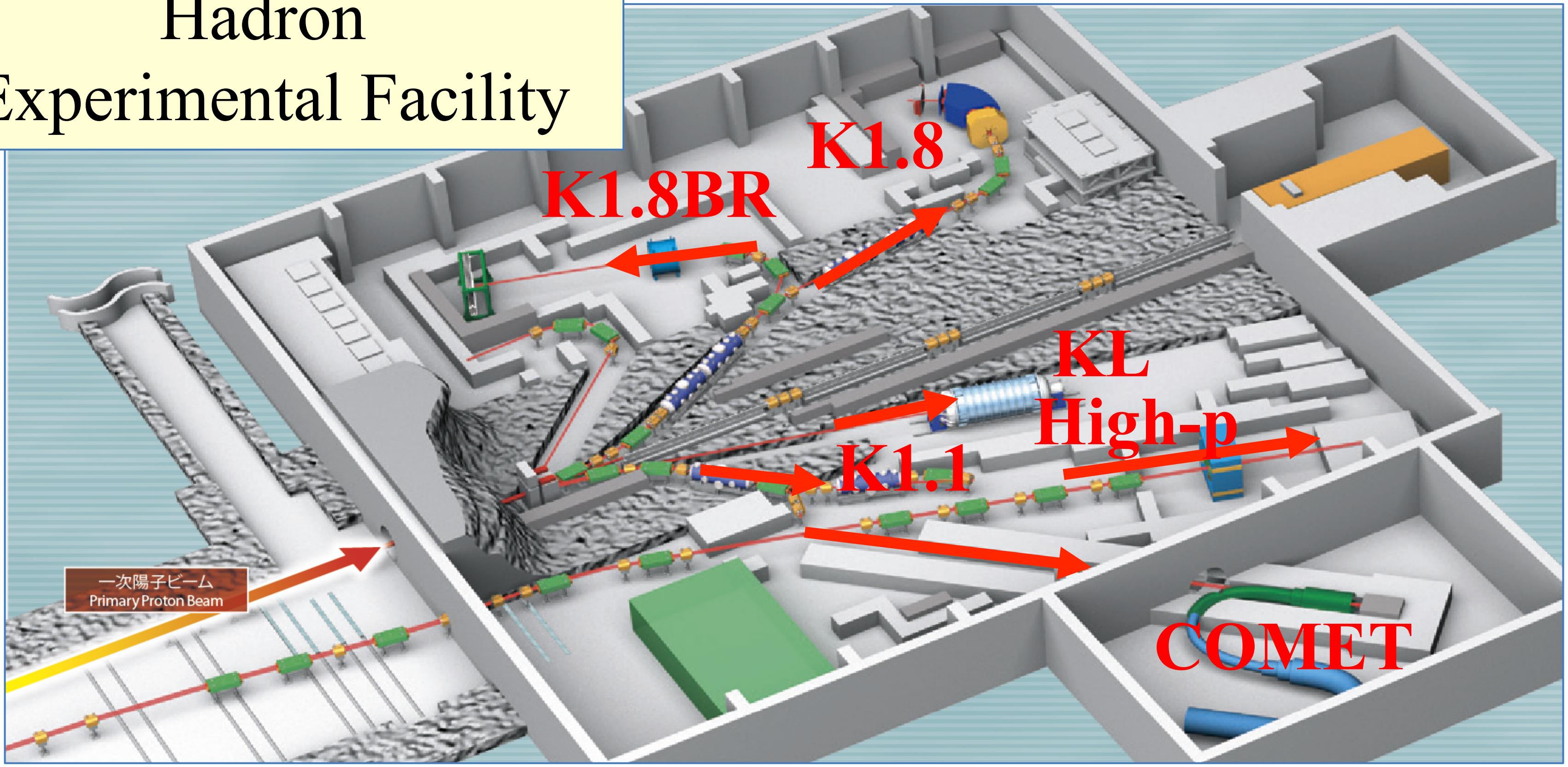

J-PARC
Tokai, Japan
(Japan Proton Accelerator Research Complex)
Material and Life Science Facility
MR
30 GeV Synchrotron
400 MeV Linac
RCS
3 GeV Synchrotron
Neutrino Experimental Facility
Hadron Experimental Facility
60m x 56m

30 GeV Accelerator & Hadron Experimental Facility



Hadron Experimental Facility



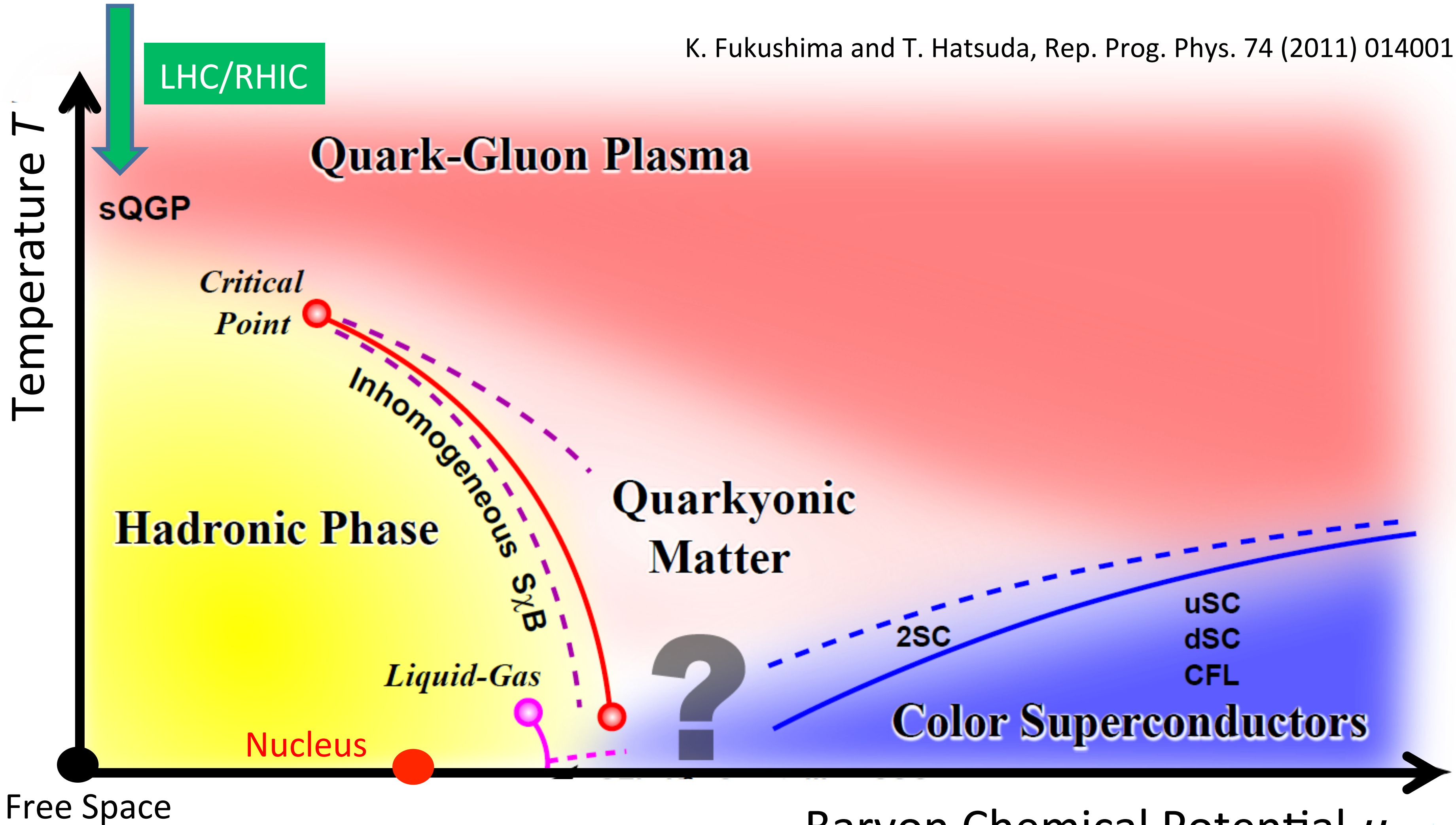
Name	Species	Energy	Intensity
K1.8	$\pi^{\pm}$, $K^{\pm}$	< 2.0 GeV/c	~10^5 Hz for K^+
K1.8BR	$\pi^{\pm}$, $K^{\pm}$	< 1.0 GeV/c	~ 10^4 Hz for K^+
K1.1	$\pi^{\pm}$, $K^{\pm}$	< 1.1 GeV/c	~ 10^4 Hz for K^+
High-p	proton	30GeV	~ 10^{10} Hz
	Unseparated	< 20GeV/c	~ 10^8 Hz

Under Construction

QCD medium

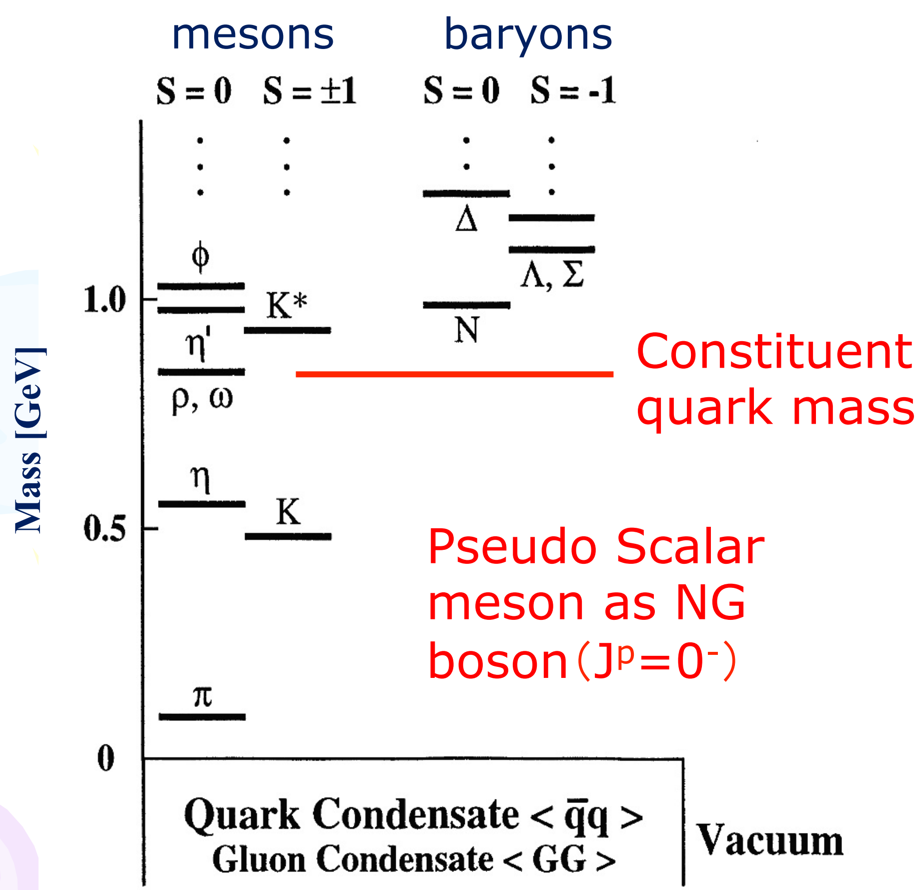
QCD: Quantum Chromo Dynamics

K. Fukushima and T. Hatsuda, Rep. Prog. Phys. 74 (2011) 014001



Nucleus is a stable and dense matter!

Hadron and QCD medium



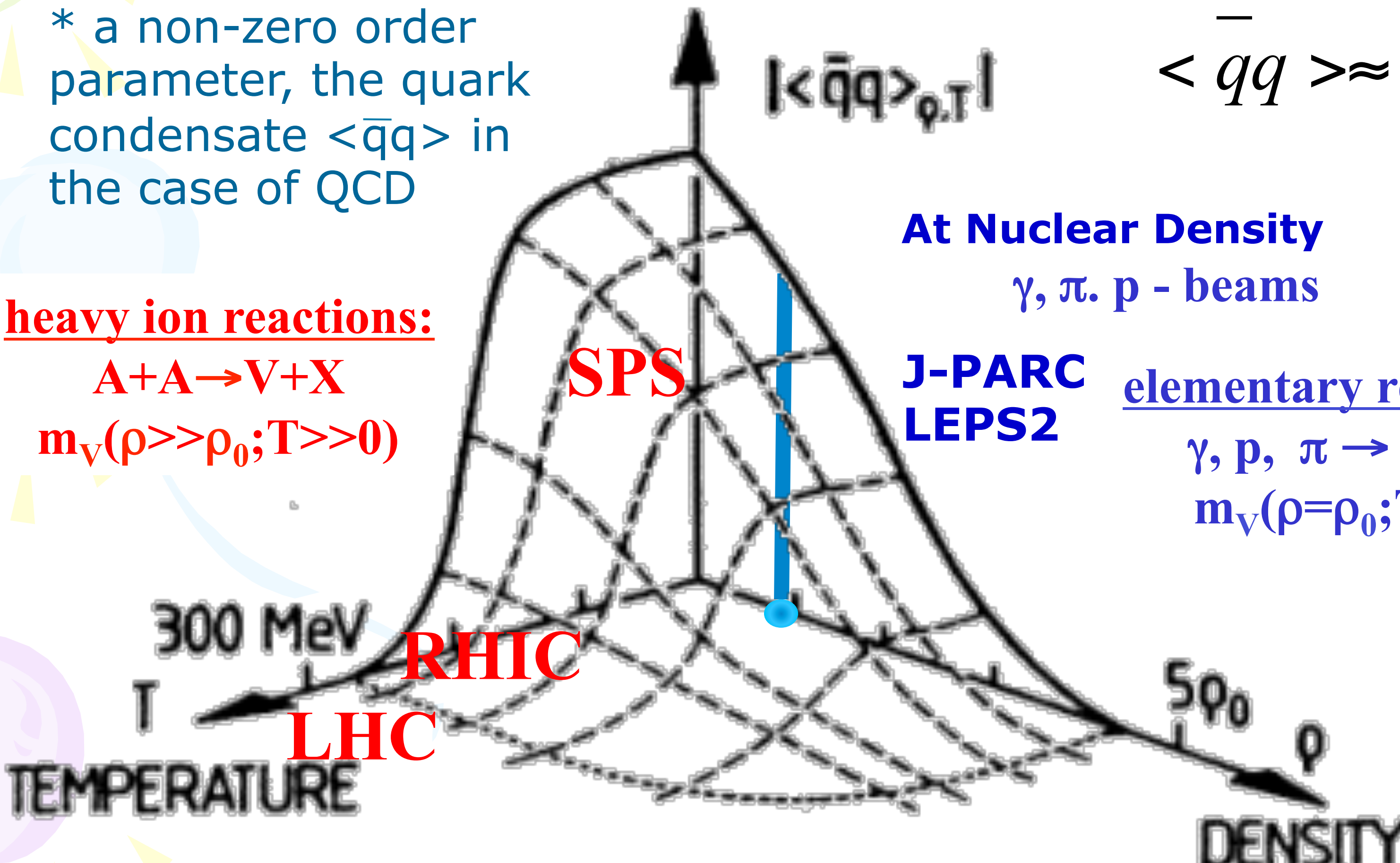
- Hadron mass is understood a sum of constituent quark masses
  - Dynamical mass
- The fact that π meson has a "too light" mass (M_π ~ 130 MeV/c^2) is understood as NG boson of chiral symmetry breaking.
- In fact, chiral symmetry is broken in the real world.
  - masses of chiral partners are different.
  - ρ ($J^P = 1^-$) m=770 MeV
    a_1 ($J^P = 1^+$) m=1250 MeV

QCD phase and $<\bar{q}q>$

$$< \bar{q}q > \approx 250 MeV^3$$

$$< \bar{q}q > \approx 0$$ **High T** **High ρ**

- Spontaneous breaking of a symmetry is marked by:
  - * a non-zero order parameter, the quark condensate $<\bar{q}q>$ in the case of QCD



heavy ion reactions:

A+A→V+X

$m_V(\rho>>\rho_0;T>>0)$

At Nuclear Density

γ, π. p - beams

J-PARC
LEPS2

elementary reaction:

γ, p, π → V+X

$m_V(\rho=\rho_0;T=0)$

We can study medium property as functions of T and ρ.

Observables

However, the quark condensate is not an observable and one need to find observables which are related to the quark condensate.

We need to find out observables related to quark condensates. Relations between mass spectra of V-AV mesons and condensates is developed using a sum rule.

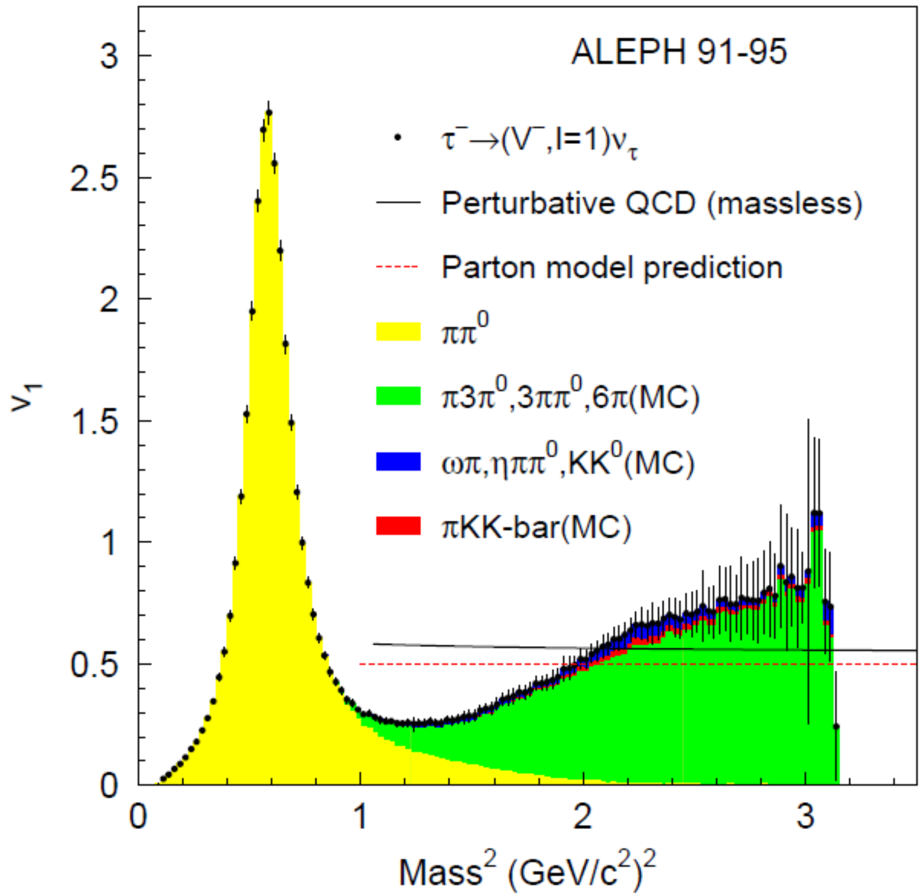
Hatsuda, Koike and Lee, Nucl. Phys. B394 (1993) 221
Kapusta and Shuryak, Phys. Rev. D49 (1994) 4694

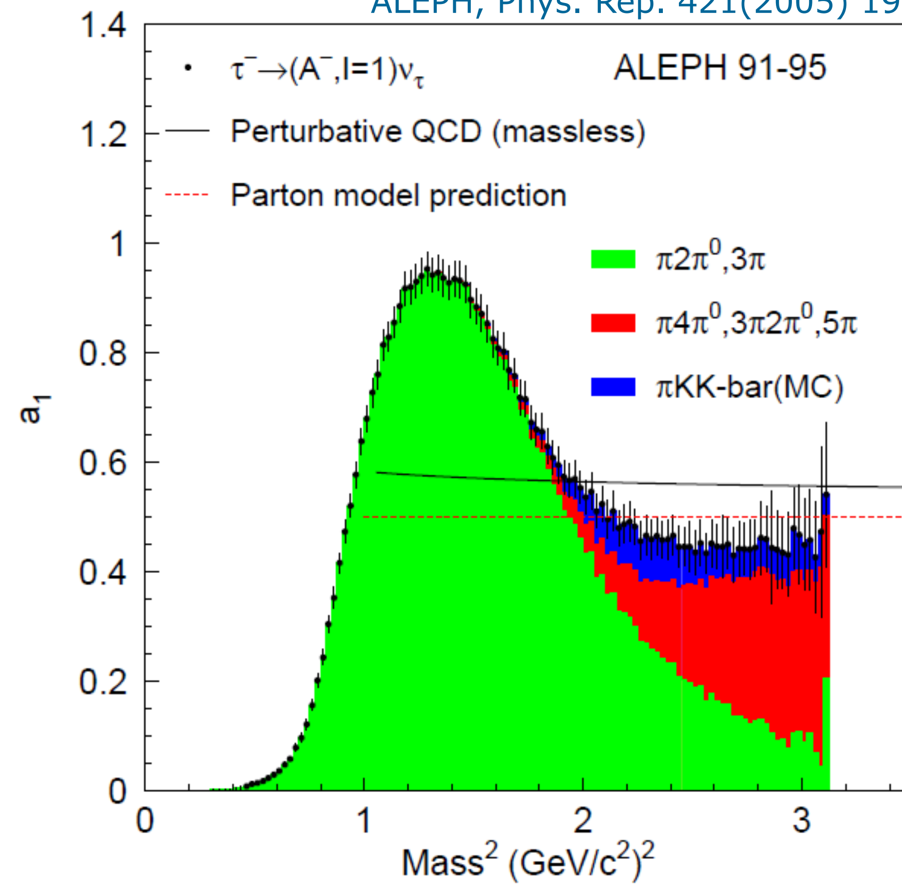
$$\int_0^\infty d\omega^2 \omega^2 (\rho_V(\omega) - \rho_A(\omega)) = -\frac{4\pi}{3}\alpha_s \langle \mathcal{O}_{4q} \rangle$$

In free space, there is a good measurement done by ALEPH group.
（ALEPH, Phys. Rep. 421(2005) 191） See the next slide.

Condensates and spectra

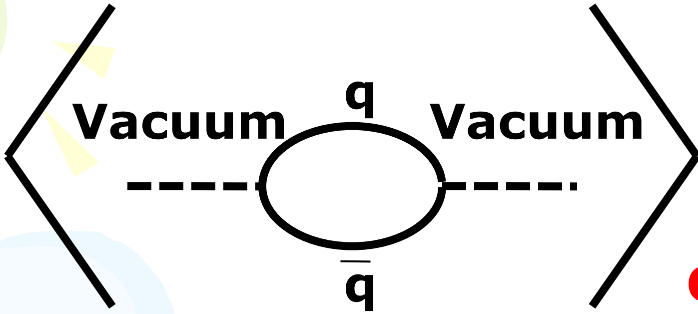
ALEPH, Phys. Rep. 421(2005) 191





QCD Sum rule

Measurements of axial vector mesons in a medium is difficult.
Different type of sum rule is proposed.

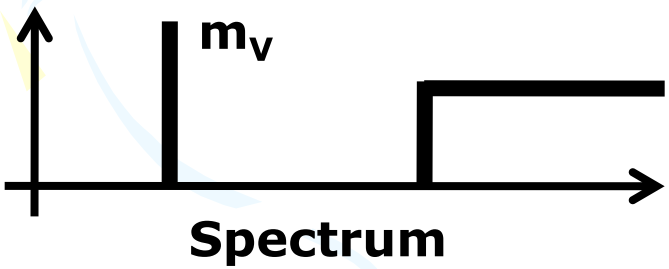


QCD sum rule

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

Example:

Theoretical Assumption



Prediction

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

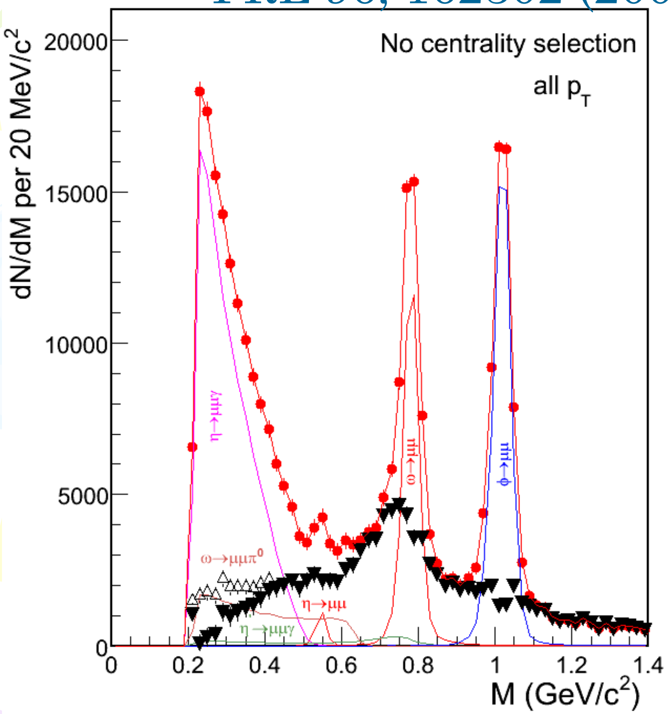
$$\frac{m_V^*}{m_V} = \left(1 - \alpha \frac{\rho_B}{\rho_0}\right) \ ; \ \alpha \approx 0.03$$

Measurements of vector mesons can be done in nucleus and high energy collisions.

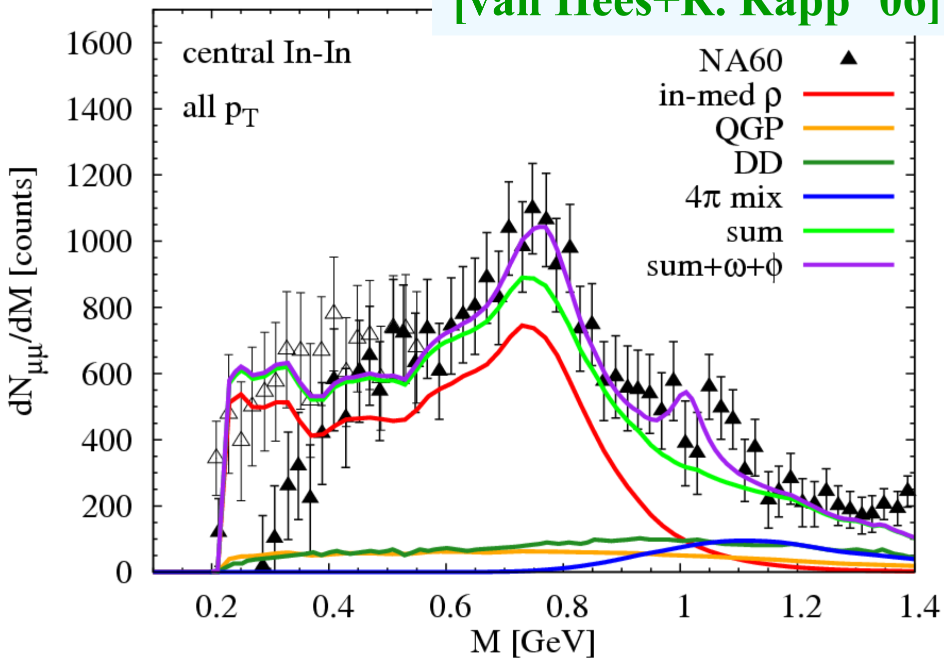
NA60 Results @ SPS

Muon pair invariant mass in Pb-Pb at $\sqrt{s_{NN}}$=19.6 GeV

PRL 96, 162302 (2006)

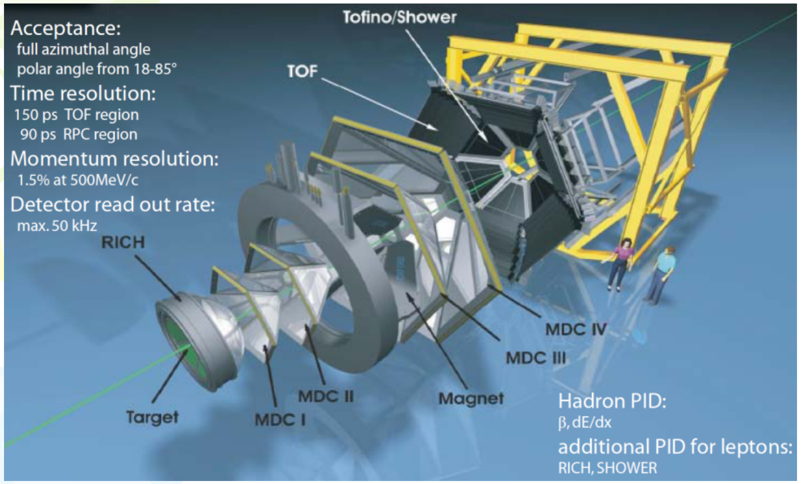


[van Hees+R. Rapp '06]

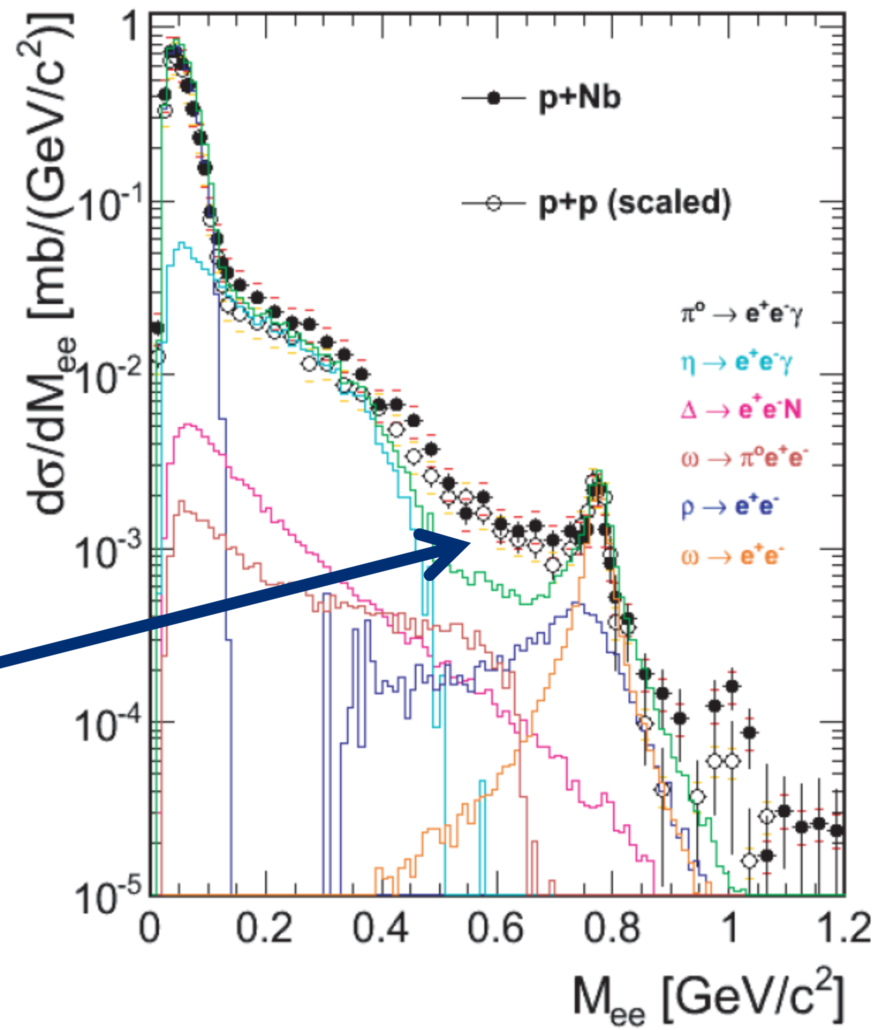


Mass spectra is reproduced by a calculation based on hadron interaction.
Evaluation of condensates should be done.

HADES@GSI



G. Agakishiev et al. Eur.Phys.J. A 48 64 (2012).



Proton beam energy at 3.5 GeV

Enhancement both for p+p and p+Nb?!

They claim effects of N* resonances.

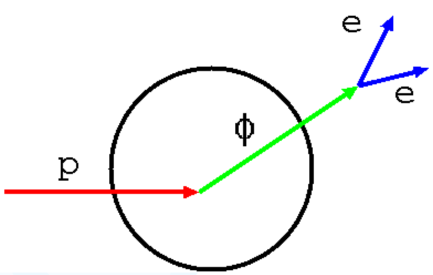
In pA (KEK-PS E325)

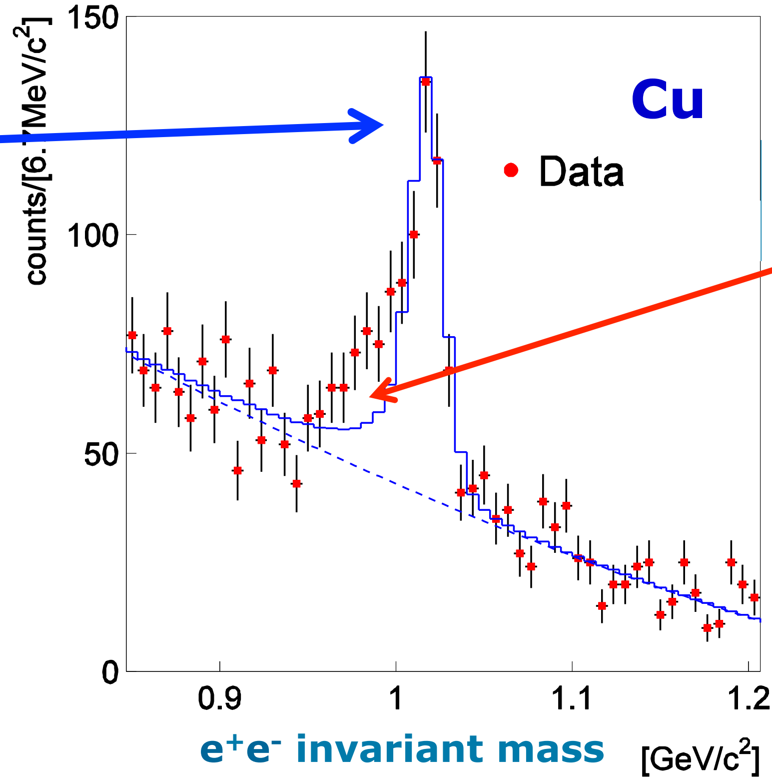
12 GeV proton induced.
p+A → ϕ + X
Electrons from ϕ decays are detected.

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

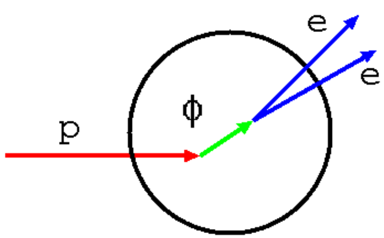
$\beta\gamma$<1.25 (Slow)

Decays **outside** nucleus





Decays **inside** nucleus



ϕmeson has NO mass modification

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

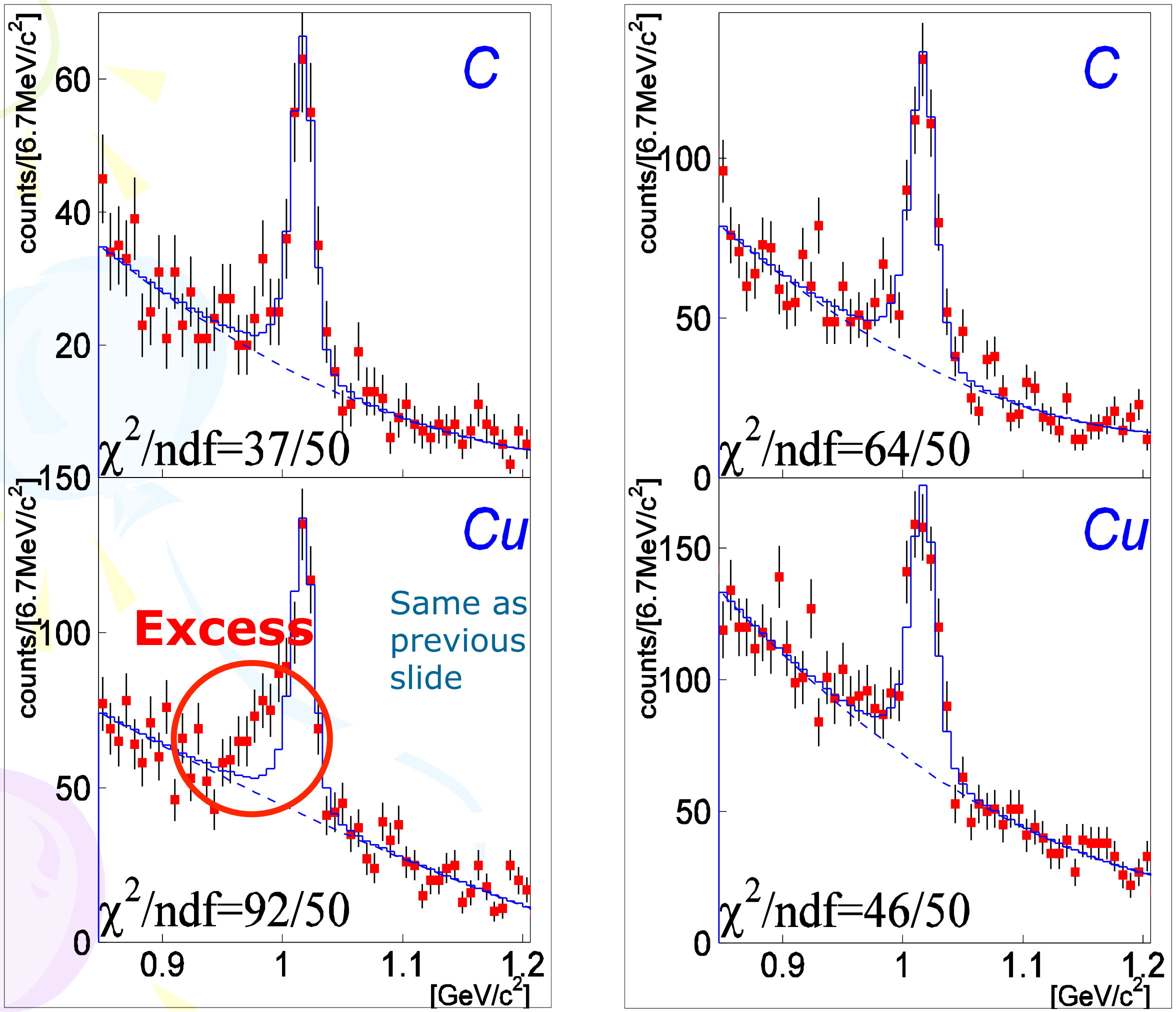
ϕmeson has mass modification

Modification is shown as an **Excess**

Indication of mass modification!

Target/Momentum dep.

$\beta\gamma<1.25$ (Slow) **$1.25<\beta\gamma<1.75$**



e^+e^- invariant mass

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

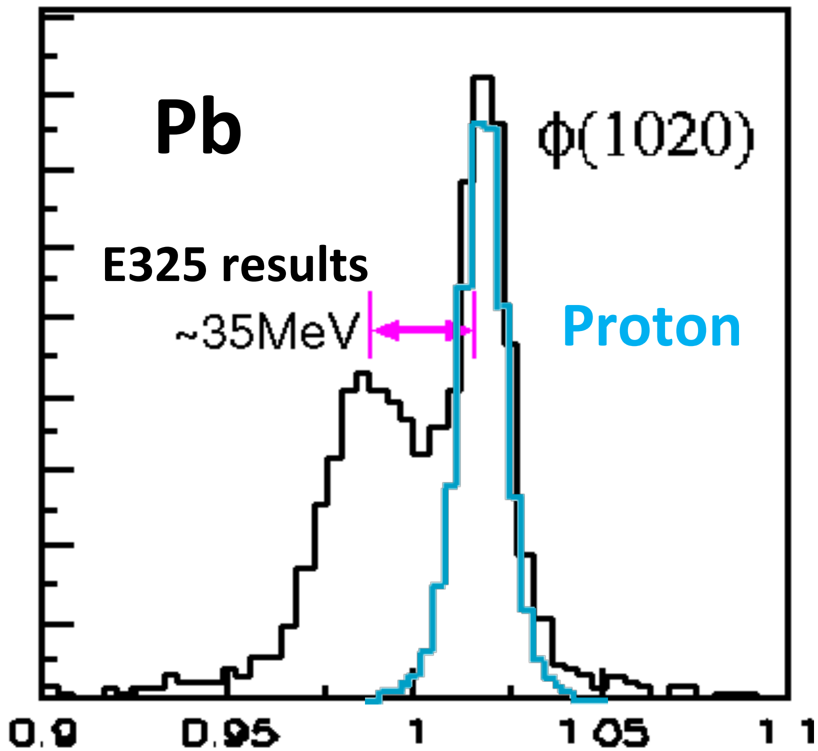
Momentum bin
- **Slowly moving ϕ mesons** have larger chance to decay inside nucleus

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

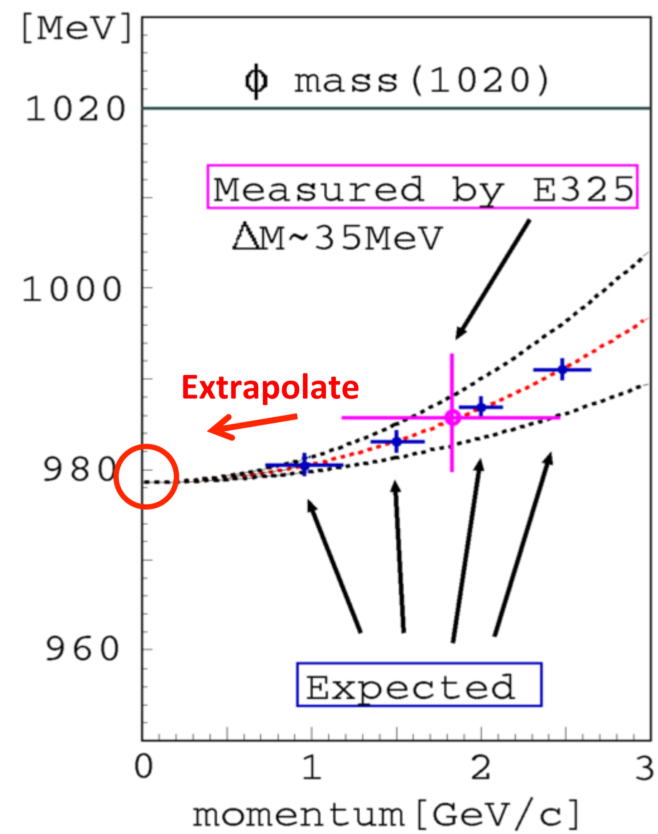
To see clear mass modification, significantly larger statistics are required.

New Goal @ J-PARC

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



Momentum Dependence



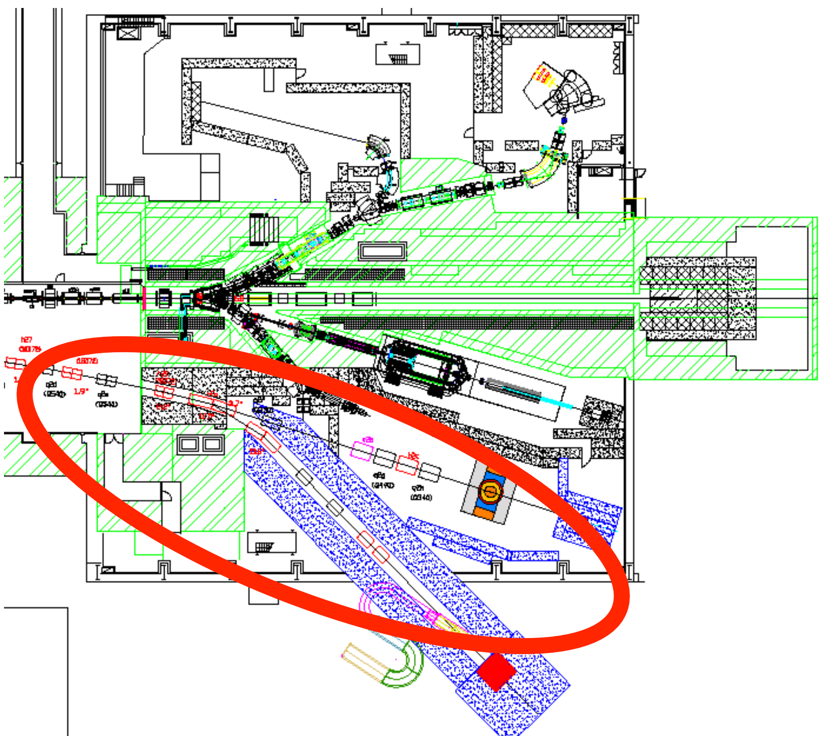
Target: 100 times larger statistics

Experimental set up

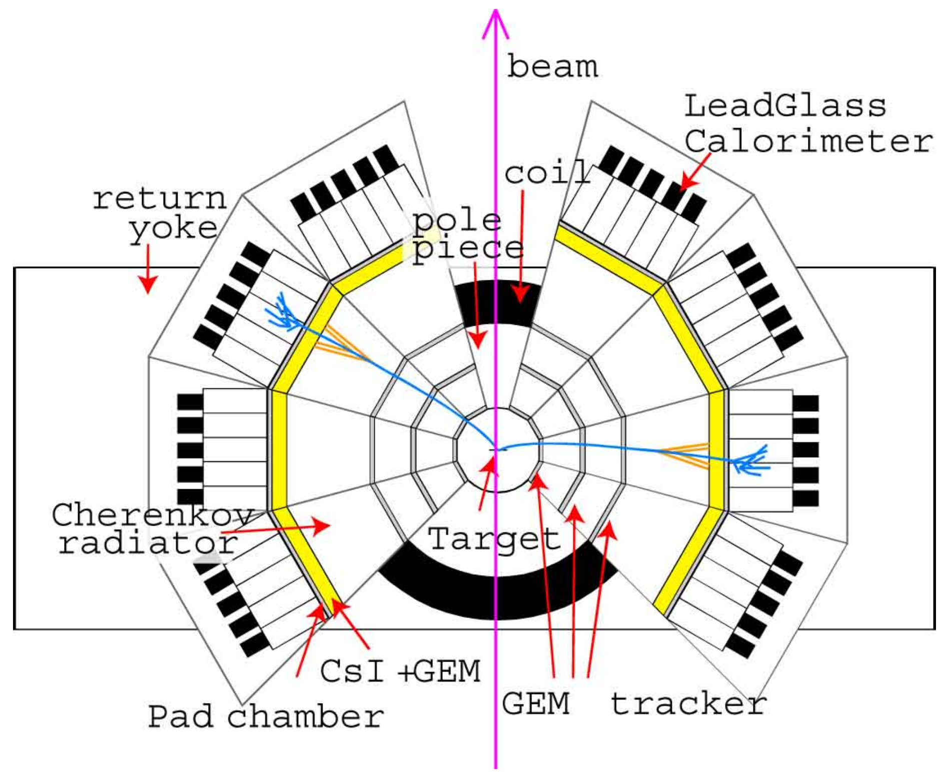
Construct a new beam line and new spectrometer

Deliver 10^{10} per spill proton beam
Primary proton (30GeV) beam

Cope with 10^{10} per spill beam intensity (x10)
Extended acceptance (90° in vertical) (x5)
Increase cross section (x2)



New high momentum beam line



Further physics opportunities

- We are planning to have hadron identification detectors in the spectrometer to extend physics opportunities.

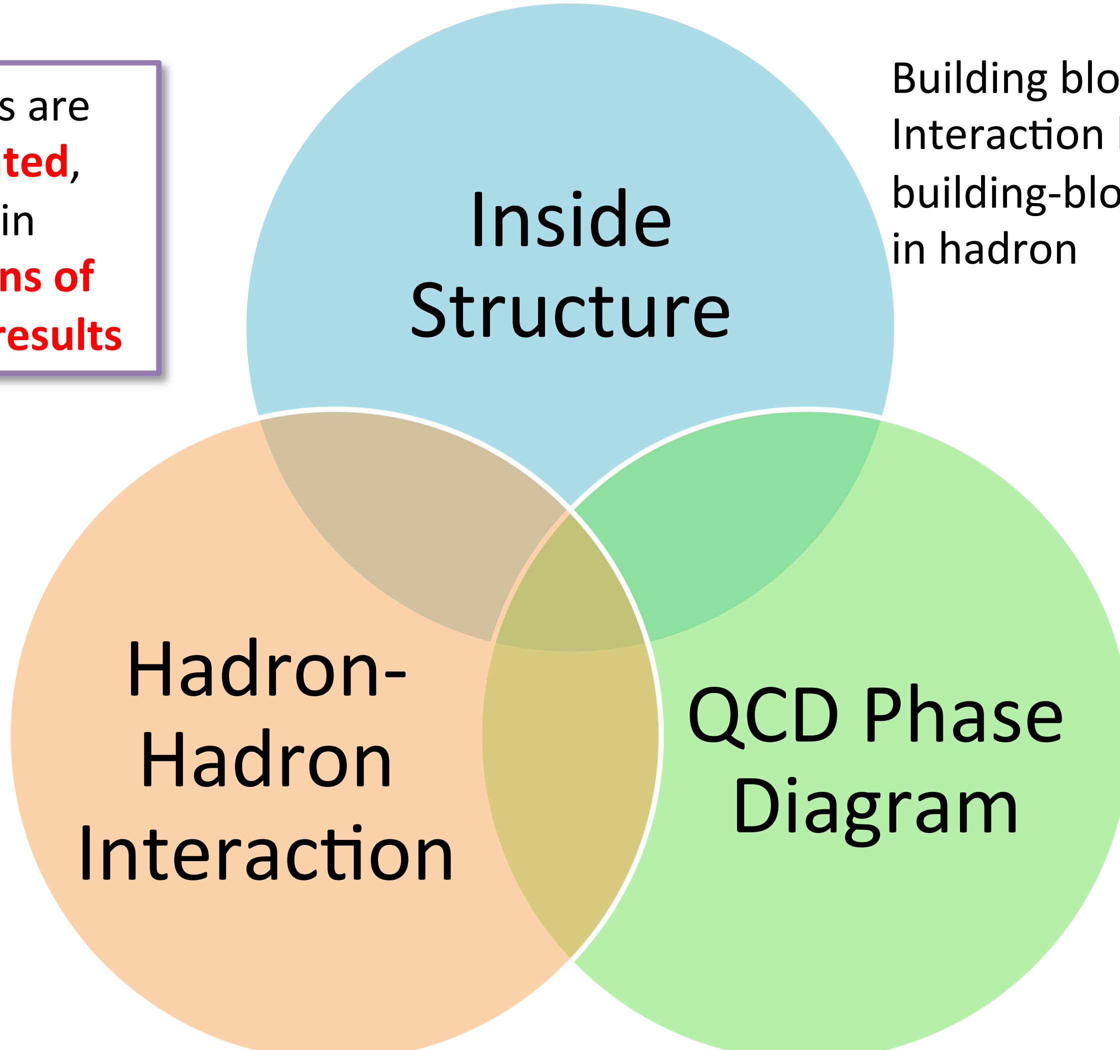
- Cross over between Quark and Hadron
  - Multi-hadron production and Correlation measurements for several energies and reaction systems are important
    - Experimental information of Multi-hadron production in pp and pA reactions are limited
  - Effects of hadron-hadron interactions should be understood in terms of high energy HI physics.
    - When we found an interesting object for our physics, then we should take a comprehensive data. Then, one can figure out what kind of physics have a main role in our data.

- As a future plan, heavy ion beam at J-PARC is under discussion.

Aspects of hadron physics

These aspects are **strongly related**, especially in **interpretations of experimental results**

Building blocks?
Interaction btw building-blocks in hadron



Interaction btw "color-less" particles

QCD medium and hadron properties

Summary

- J-PARC is the nearest experimental facility for hadron physics.
- Chiral properties of QCD medium are studied using measurements of vector meson mass spectra.
- Several measurements are already done using AA and pA collisions to investigate high temperature or high density matters.
- Results show modifications of mass spectra. To study more details of chiral properties, higher statistics and better resolution. Such experiments will be done at J-PARC.

BACKUPS

Chiral symmetry

QCD Lagrangian

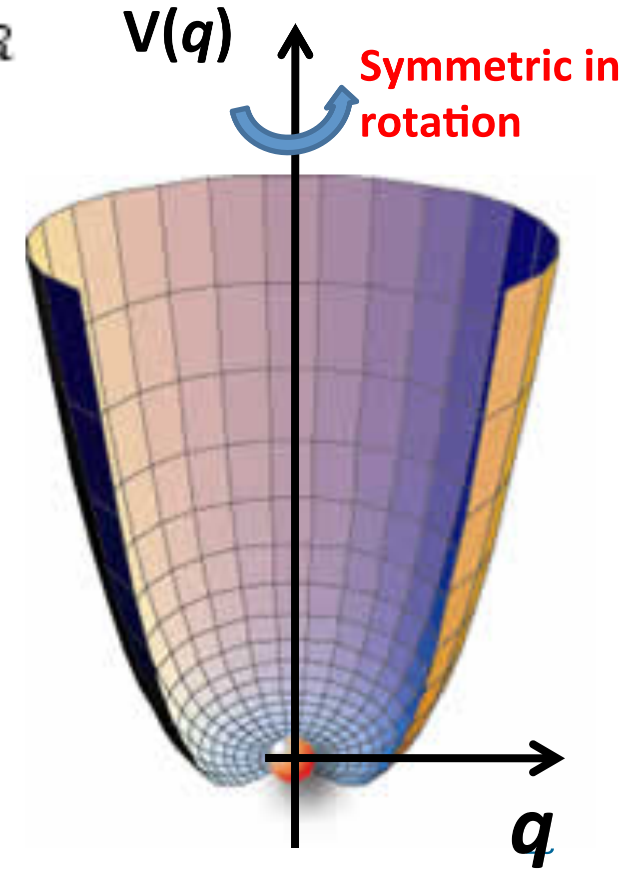
$$\mathcal{L} = -\frac{1}{4}F^{\alpha}_{\mu\nu}F^{\mu\nu}_{\alpha} - \sum_n \bar{q}_n\gamma^{\mu}[\partial_{\mu} - igA^{\alpha}_{\mu}t_{\alpha}]q_n - \sum_n m_n\bar{q}_n q_n$$

Gluon **quark** **mass**

Divide with chirality

Neglect (if m ~0)

$$\mathcal{L} = -\frac{1}{4}F^{\alpha}_{\mu\nu}F^{\mu\nu}_{\alpha} + \bar{q}_L i\not{D} q_L + \bar{q}_R i\not{D} q_R$$



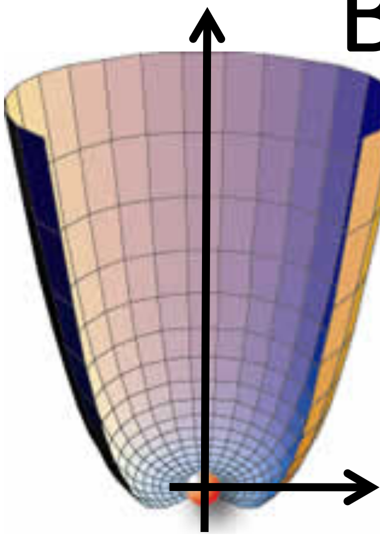
The lagrangian does not change under the transformation below.

$$q_L \rightarrow e^{-i\frac{\vec{\tau}}{2}\vec{\Theta}_L}\, q_L$$
$$q_R \rightarrow e^{-i\frac{\vec{\tau}}{2}\vec{\Theta}_R}\, q_R$$

This symmetry is called **Chiral symmetry**.

Breaking of symmetry

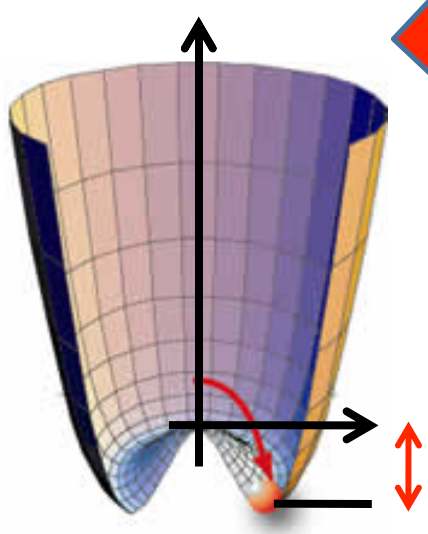
When the potential is like $V(\phi) = \phi^4$,



Potential is symmetric and
Ground state (vacuum) is at symmetric position

If the interaction generate additional potential automatically,

$$V'(\phi) = -a*\phi^2$$

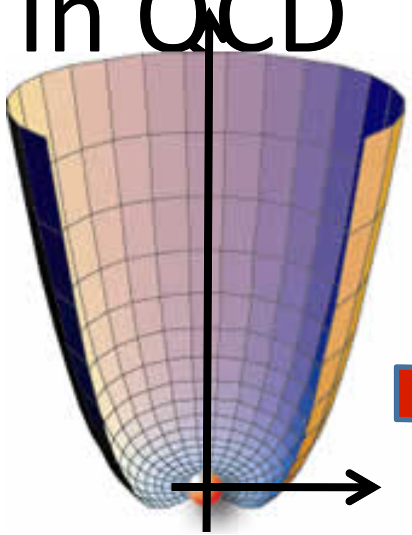


Potential is still symmetric, however,
Ground state (vacuum) is at **non-symmetric** position

This phenomenon is called **spontaneous symmetry breaking**

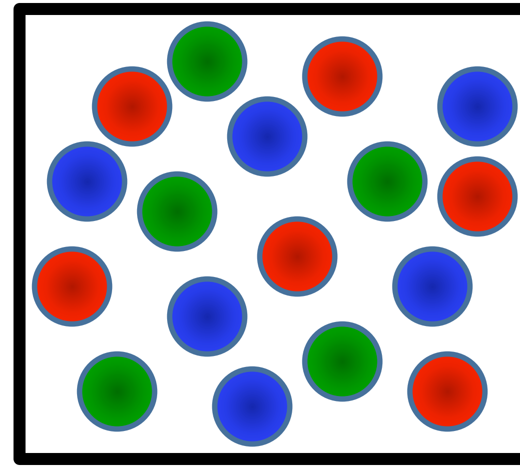
δV
~ self energy of ground state ~ mass

In QCD

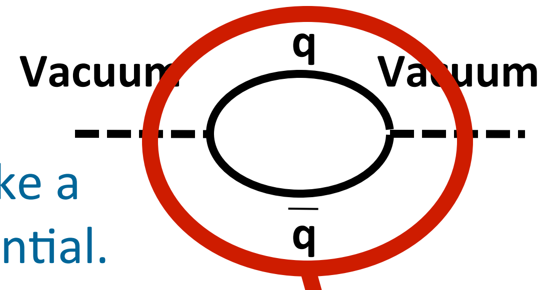


High Temperature
High Density

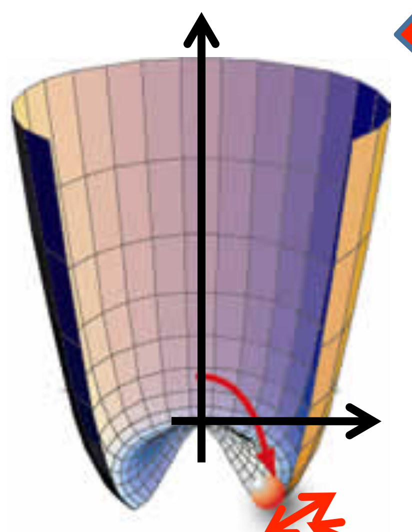
Chiral symmetry exists.
Mass ~ 0 (Higgs only)

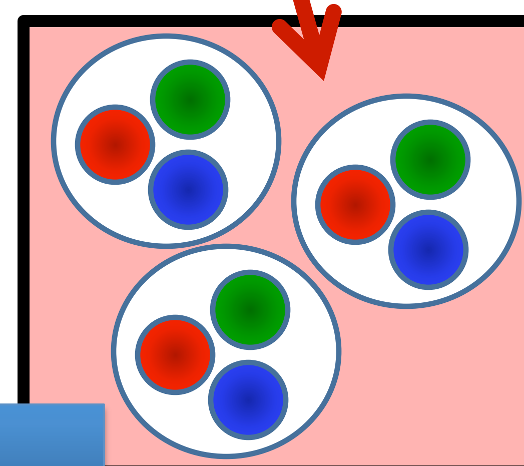


When T and ρ is going down,



Quark – antiquark pairs make a condensate and give a potential. Chiral
symmetry is breaking, spontaneously.



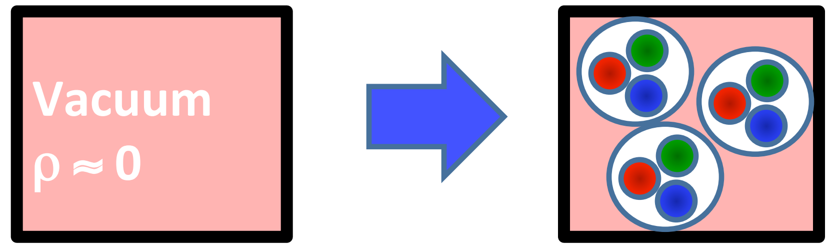


Vacuum contains quark antiquark condensates.
So called **"QCD vacuum".**

π as a Nambu-Goldstone boson.

How to study more details?

"QCD medium", i.e. quark condensates can be changed in finite density or temperature matter.
Then, chiral symmetry will be restored (partially).



In finite ρ/T

Chiral properties can be studied at finite density or temperature.

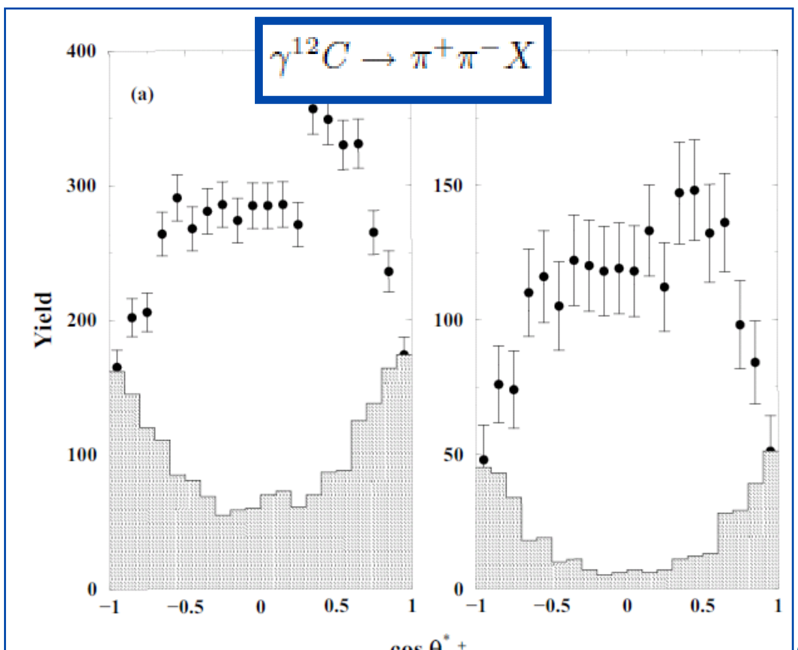
Nucleus can be used as a finite density system.
High energy heavy ion collisions can generate a high temperature matter

Chiral property of the medium is characterized by a quark condensate.
The quark condensate is an order parameter of chiral symmetry.

INS-ES TAGX experiment

Eγ~0.8-1.12.GeV, sub/near-threshold ρ^0 production

- **PRL80(1998)241,PRC60:025203,1999.: mass reduced in invariant mass spectra of 3He(γ, ρ^0)X ,ρ^0 --> π+π−**
- **Phys.Lett.B528:65-72,2002: introduced cosθ analysis to quantify the strength of rho like excitation**
- **Phys.Rev.C68:065202,2003. In-medium ρ0 spectral function study via the H-2, He-3, C-12 (γ,π+ π-) reaction.**



Try many models, and channels

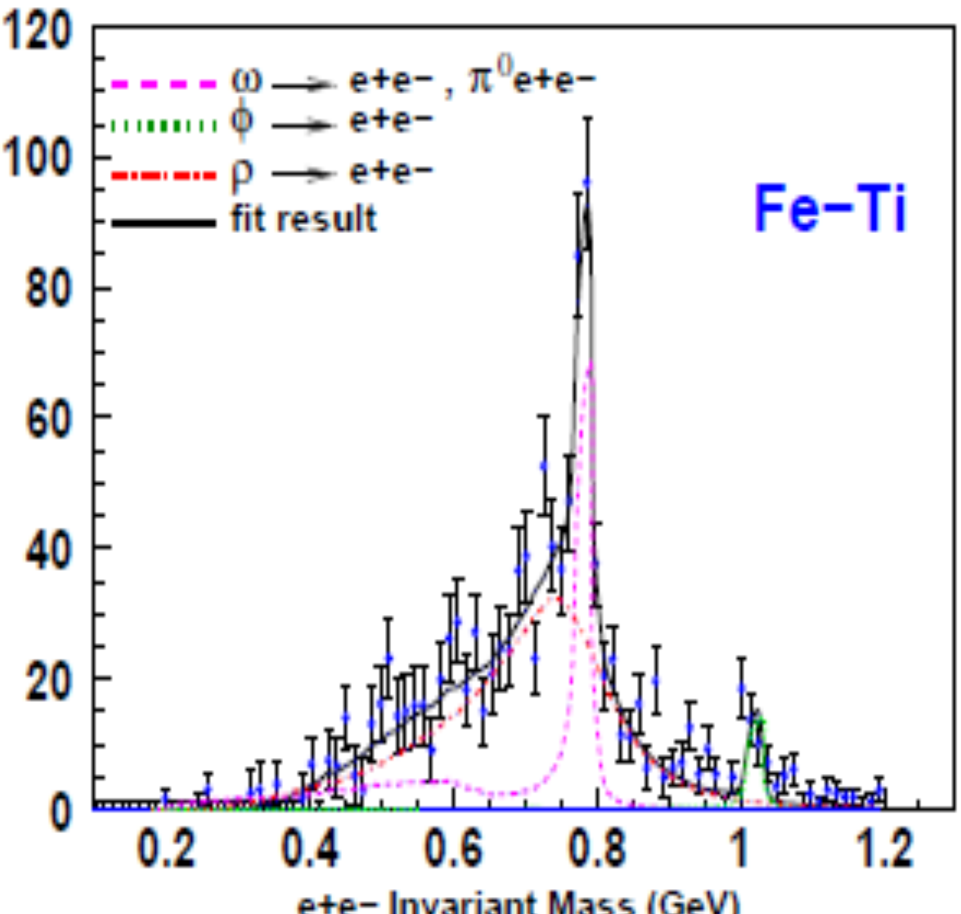
Δ, N*, 3π,…

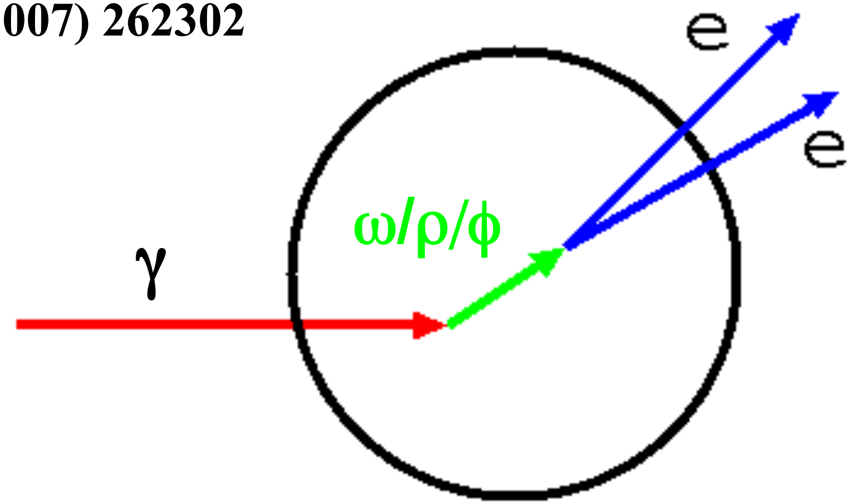
Eγ	STT model Present work	Previous work
800-960 MeV	700-710 MeV	672±31 MeV
960-1120 MeV	730 MeV	743±17 MeV

CLAS g7a @ J-Lab

Induce photons to Liquid dueterium, Carbon, Titanium and Iron targets, generate vector mesons, and detect e+e- decays with large acceptance spectrometer.

R. Nasseripour et al., PRL 99 (2007) 262302





No peak shift of ρ

Only broadening is observed

$$m_\rho = m_0 (1 - \alpha\, \rho/\rho_0)$$

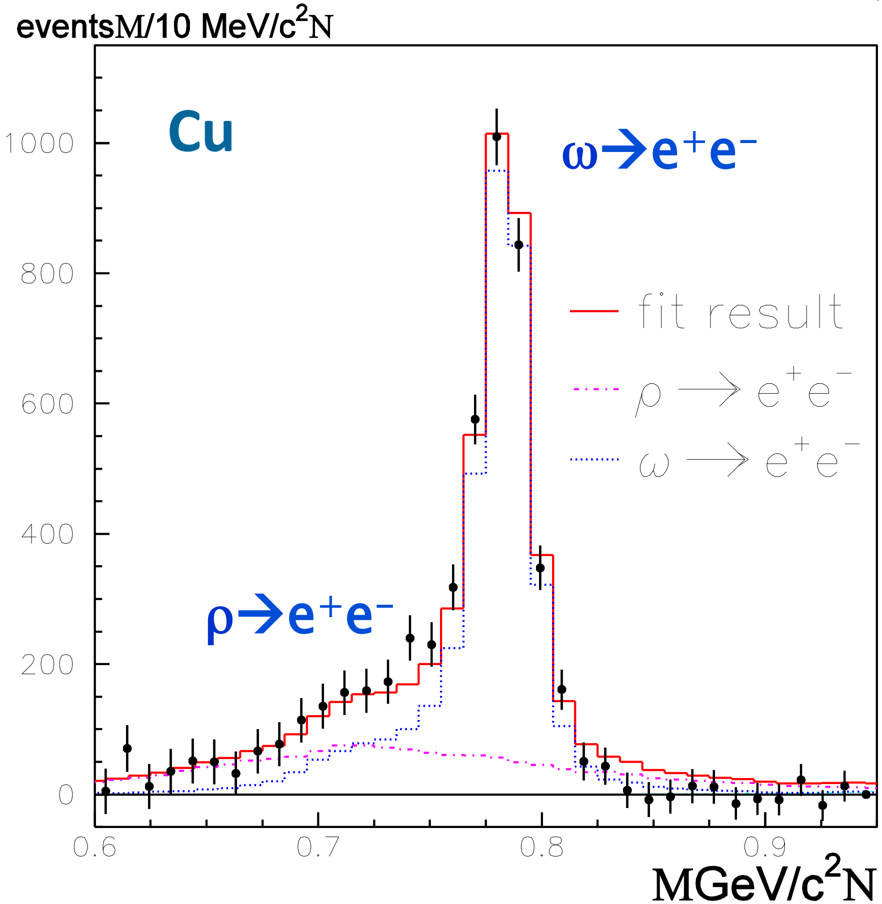
for $\alpha = 0.02 \pm 0.02$

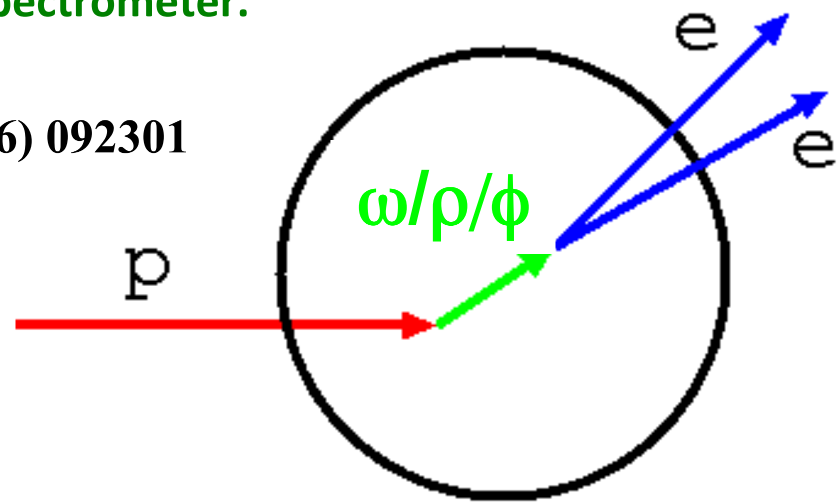
Mass spectra measurements

KEK E325, $\rho/\omega \rightarrow e^+e^-$

Induce 12 GeV protons to Carbon and Cupper target, generate vector mesons, and detect e+e- decays with large acceptance spectrometer.

M. Naruki et al., PRL 96 (2006) 092301



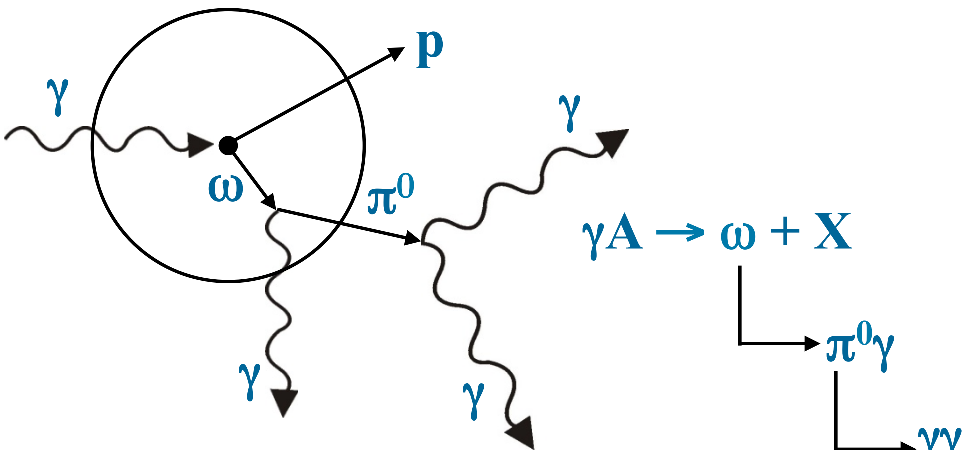


The excess over the known hadronic sources on the low mass side of ω peak has been observed.

$$m_\rho = m_0\,(1 - \alpha\,\rho/\rho_0) \quad \text{for } \alpha = 0.09$$

Results from CBELSA/TAPS

TAPS, $\omega \to \pi^0\gamma$ with γ+A



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

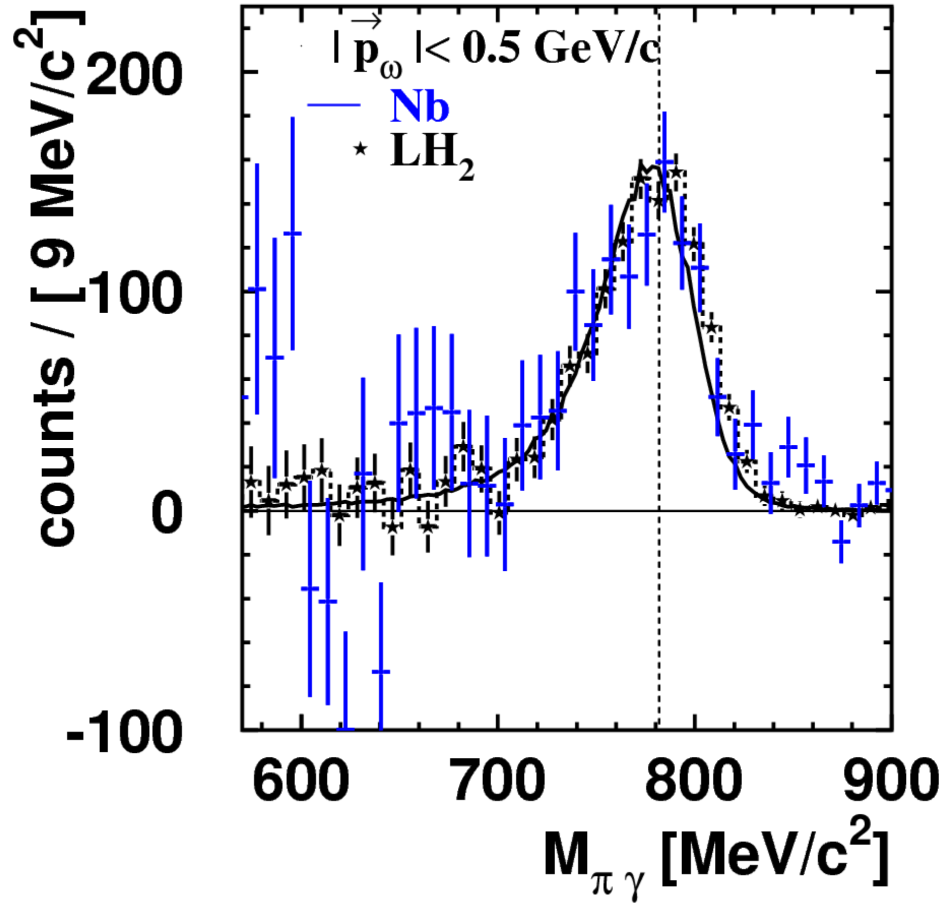
advantage:

- $\pi^0\gamma$ large branching ratio (8 %)
- no ρ-contribution ($\rho \to \pi^0\gamma : 7 \cdot 10^{-4}$)

disadvantage:

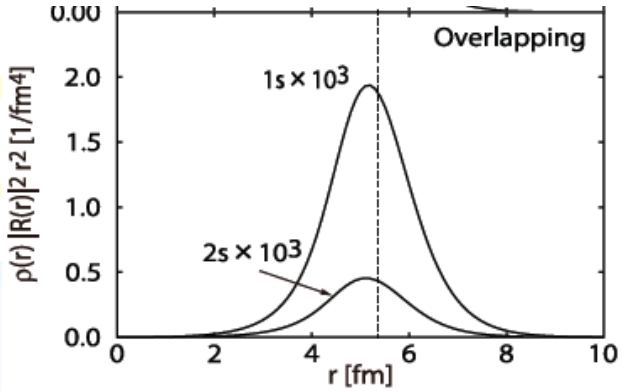
- π^0-rescattering

arXiv: 1005.5694



Deeply bound π

Large overlap of wave function



N. Ikeno *et al.*, PTP126(2011)483.

Sensitive to π-nucleus strong interaction potential

$$V_{s\text{-wave}} = b_0\,\rho + \mathbf{b_1}\,(\rho_n - \rho_p) + B_0\,\rho^2$$

Measure binding energy can be converted to this b1 information

Daisuke Jido, Tetsuo Hatsuda, Teiji Kunihro, Phys.Lett.B670:109-113,2008.
Kolomeitsev, Kaiser, Weise, Phys. Rev. Lett. 90(2003)092501

M. Gell-Mann *et al.*, PR175(1968)2195.

Gell-Mann-Oakes-Renner relation

$$f_\pi^2 m_\pi^2 = -2m_q \langle \bar{q}q \rangle$$

f_π : pion decay constant

Y. Tomozawa, NuovoCimA46(1966)707.
S. Weinberg, PRL17(1966)616.

Tomozawa-Weinberg relation

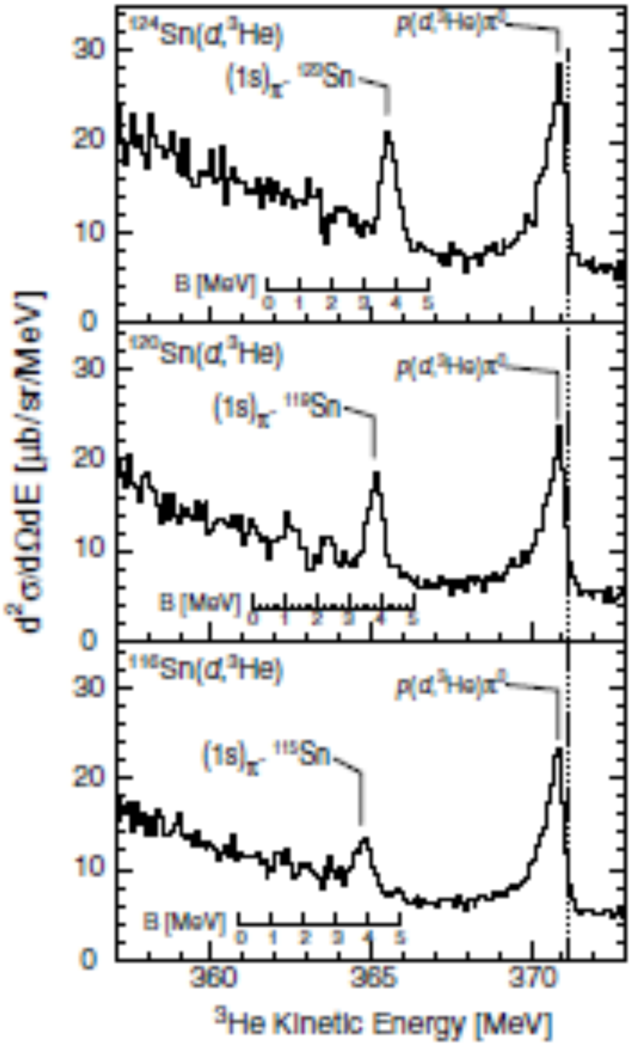
$$b_1 = -\frac{m_\pi}{8\pi f_\pi^2}$$

b_1 : isovector πN scattering length

$$\frac{\langle \bar{q}q \rangle_\rho}{\langle \bar{q}q \rangle_0} \approx \frac{b_1^{\text{free}}}{b_1(\rho)}$$

Exp. Results

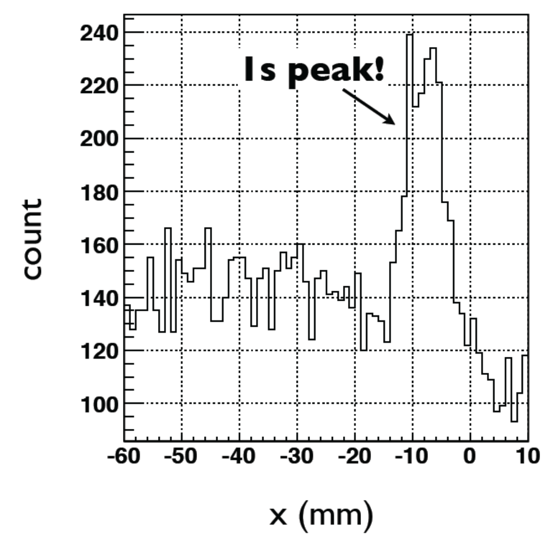
K. Suzuki et al., Phys. Rev. Let., 92(2004) 072302



π bound state is observed in Sn(d, ^{3}He) pion transfer reaction at GSI.

Reduction of the chiral order parameter, *$f^*_\pi(\rho)^2/f_\pi^2=0.64$ at the normal* nuclear density ($\rho = \rho_0$) *is indicated.*

Experiment is continued at RIKEN and positive results are already obtained.



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 uncertaint y in backgroun d

Several hadronic and experimental effects cause

How about ϕ meson?

- ρ/ω
  - Dynamical mass contribution is dominant
    M_π ~ 130 MeV/c^2 M_ρ ~ 770 MeV/c^2
  - Large hadronic effects and background issues are large
- ϕ
  - Still, dynamical mass contribution is dominant
    M_η ~ 550 MeV/c^2 M_ϕ ~ 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 pron

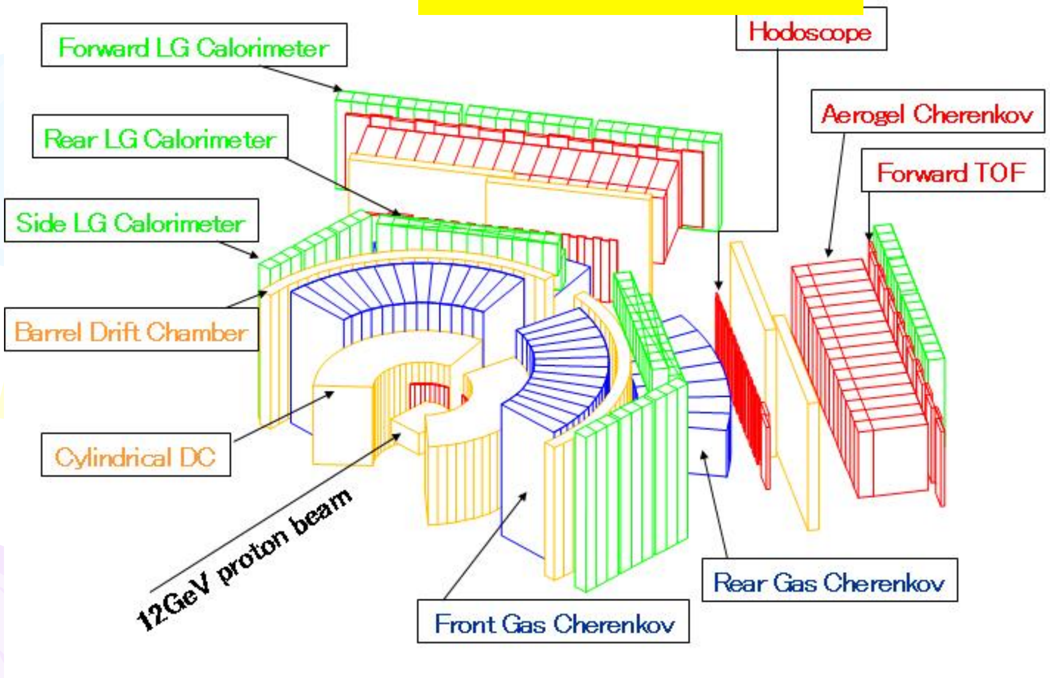
Experimental Setup

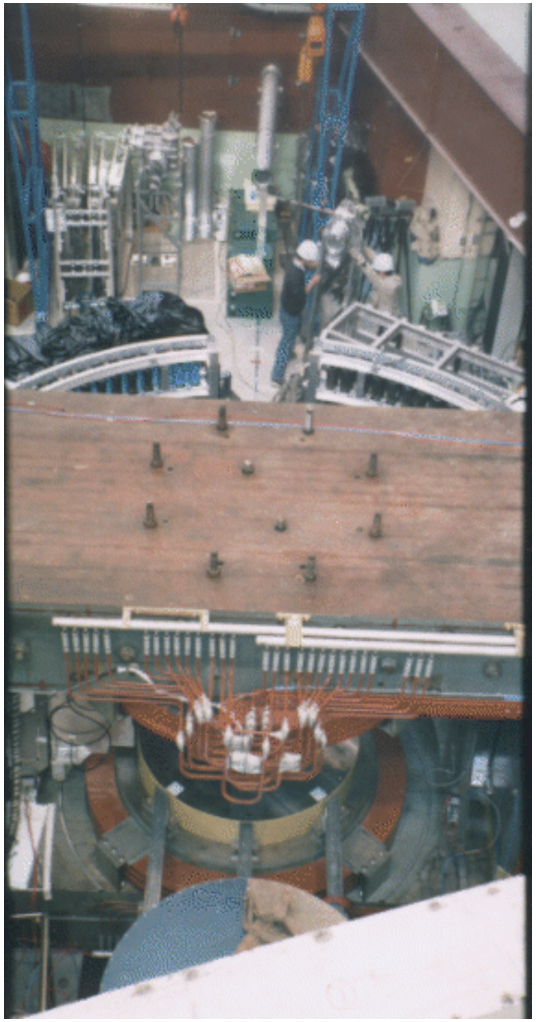
12 GeV proton induced.

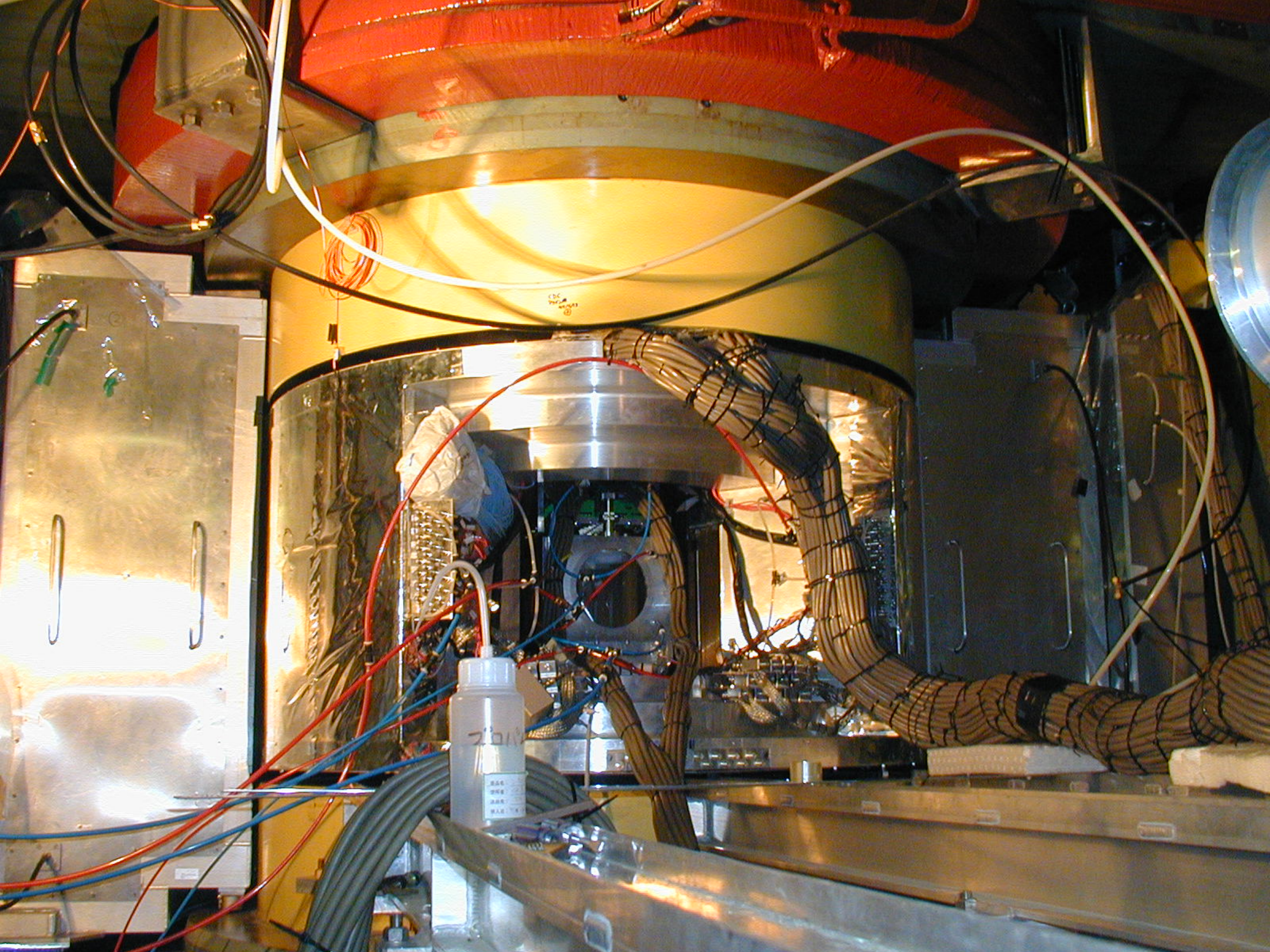
$p+A \rightarrow \phi + X$

Electrons from ϕ decays are detected.

KEK E325





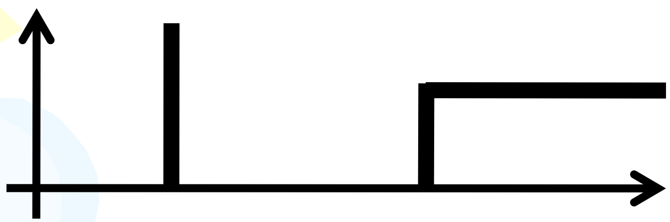


Next step

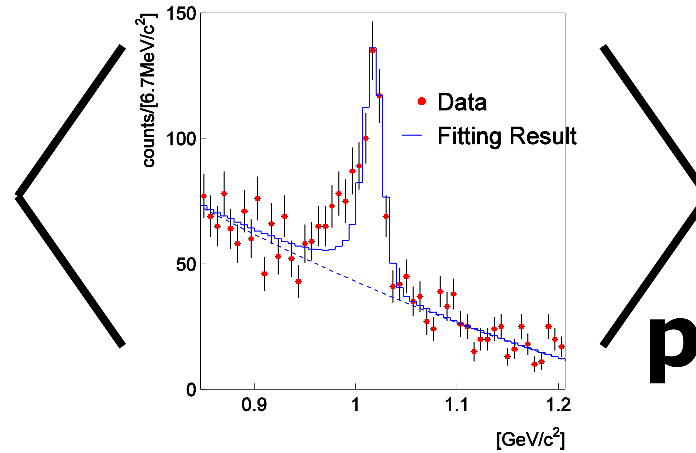
Evaluate quark condensate directly.

Replace by average of measured spectra

Average of Imaginary part of $\Pi(\omega^2)$



Assumed Spectrum

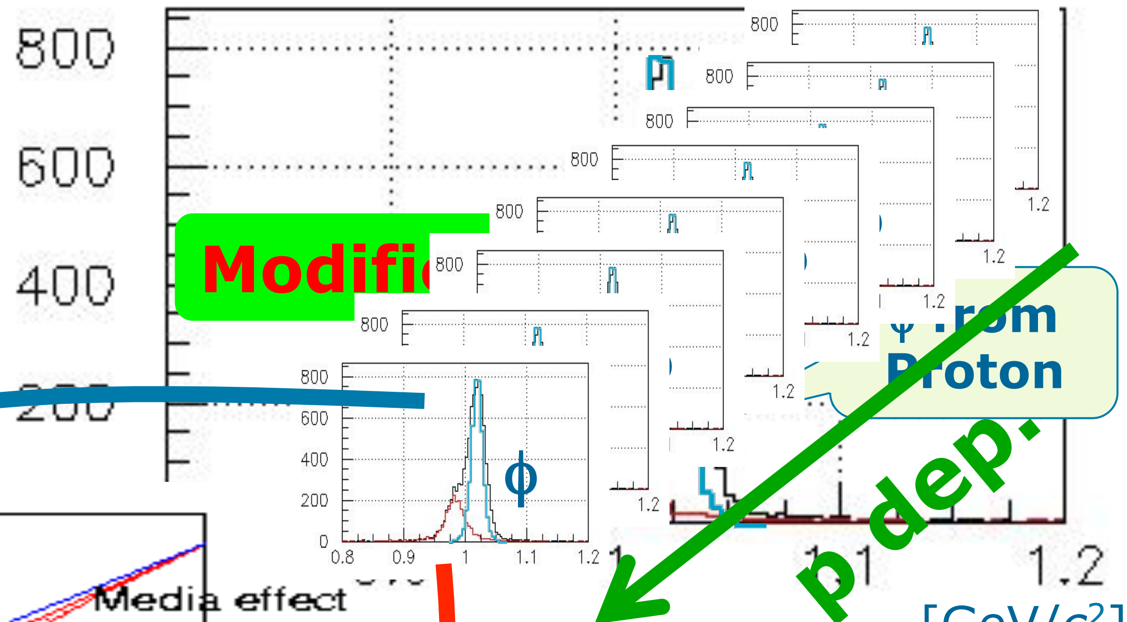


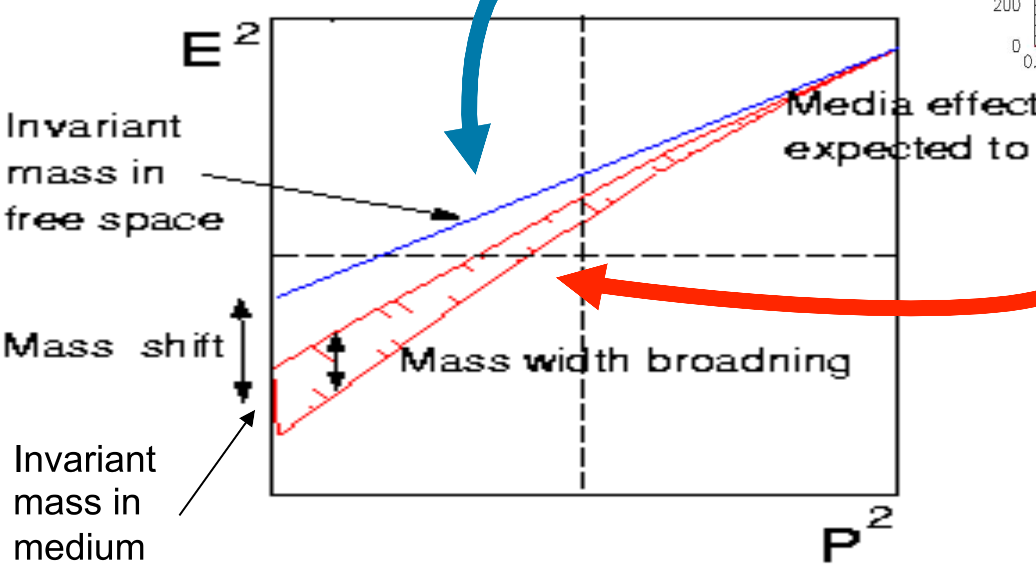
Then, calculate quark condensate using QCD sum rule.

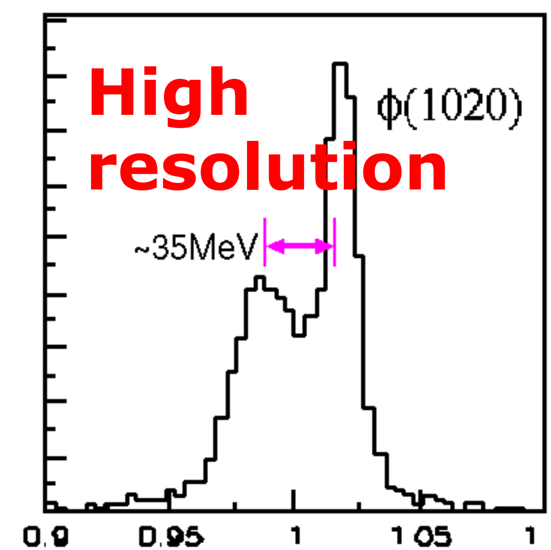
Experimental requirements

1. High statics
2. Good mass resolution

What can be achieved?







Dispersion relation

Calc. with other models

βγ<0.5 | 0.5<βγ<1.25 | βγ<0.5 | 0.5<βγ<1.25

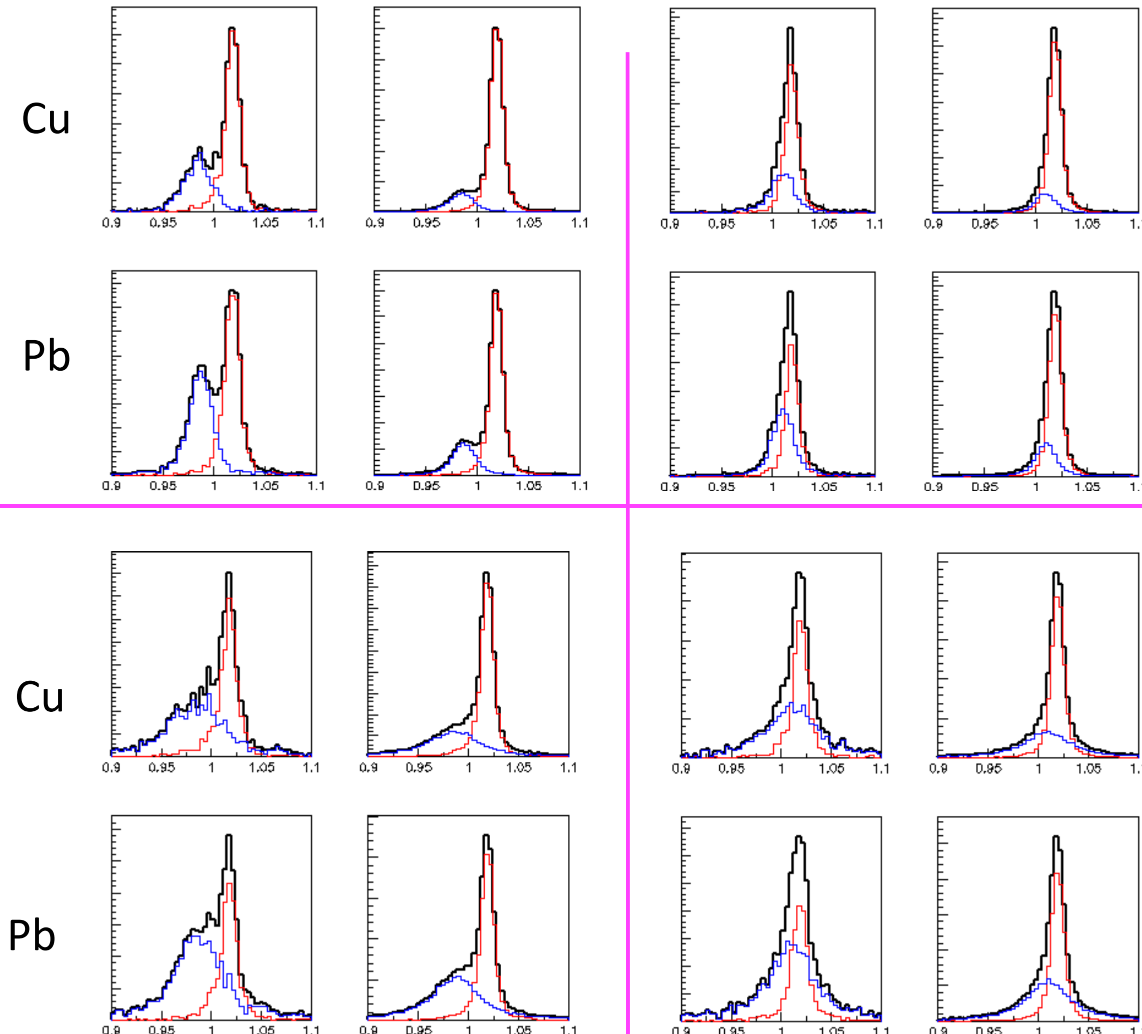
E325
Δm : 35 MeV
(28 ~ 41)
Γ : 15 MeV
(10~23)

cf. Hatsuda, Lee (PRC46, 34)
Δm : 12~44 MeV
Γ : not estimated

Oset, Ramos
(NPA 679, 616)
Δm : 10 MeV
Γ : 15 MeV
Hadronic model

Δm : 35 MeV
Γ : 50 MeV

Klingle, Waas, Weise
(PLB431,254)
Δm : 10 MeV
Γ : 50 MeV
Hadronic model



blue: decays inside nuclei **red**: decays outside nuclei

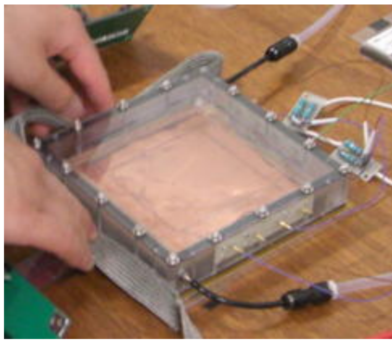
At J-PARC, clear mass spectra in nucleus will be obtained to compare with models.

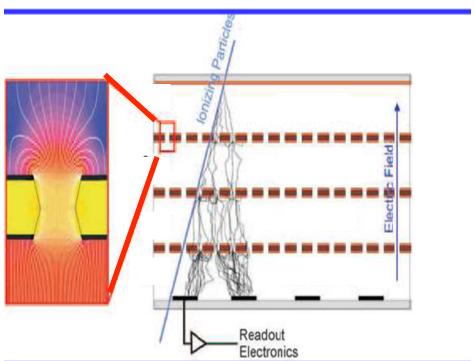
R&D Items

Develop 1 detector unit and make 26 units.

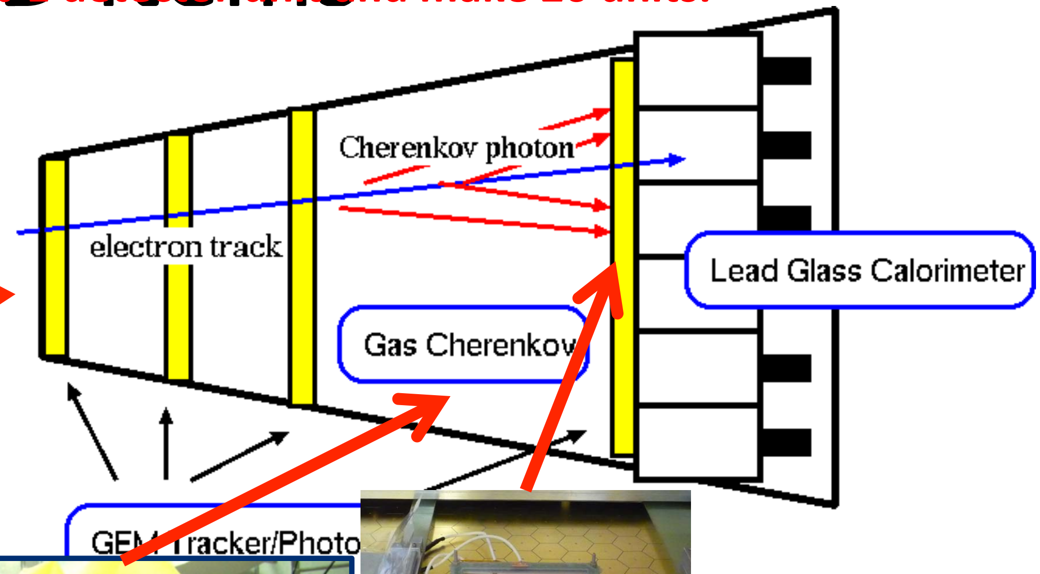
① GEM foil

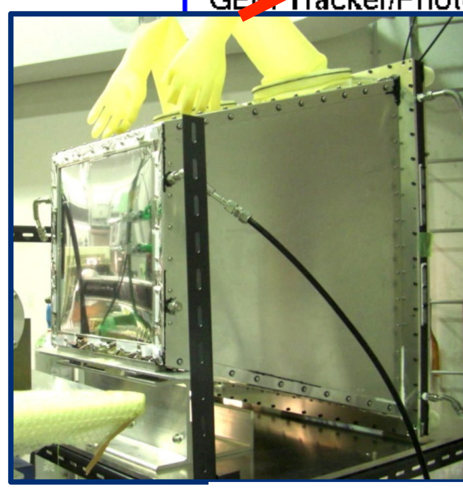
② GEM Tracker

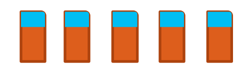




Ionization (Drift gap)
+ Multiplication (GEM)
High rate capability
+ 2D strip readout







CsI + GEM
photo-cathode

50cm gas(CF_4) radiator
~ 32 p.e. expected
CF4 also for multiplication in GEM

③ Hadron Blind detector

Gas Cherenkov for electron-ID

Detector components

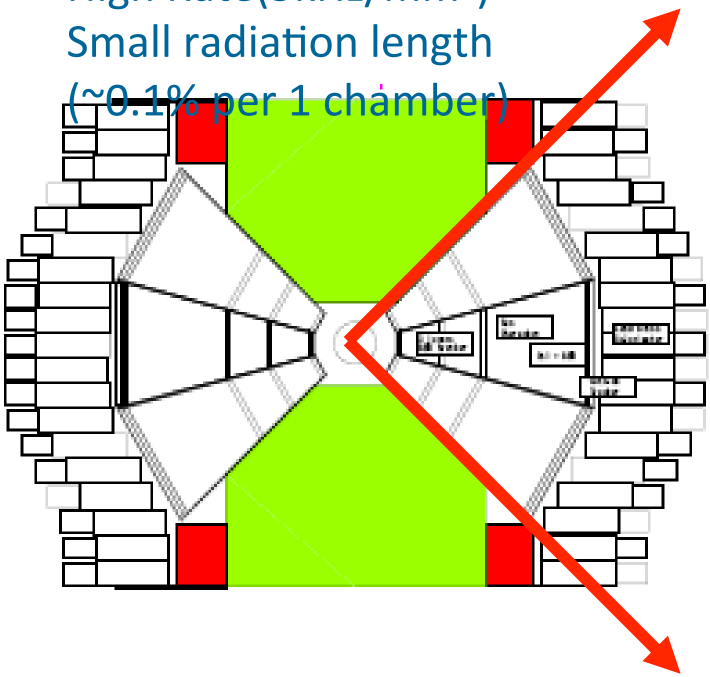
Tracker

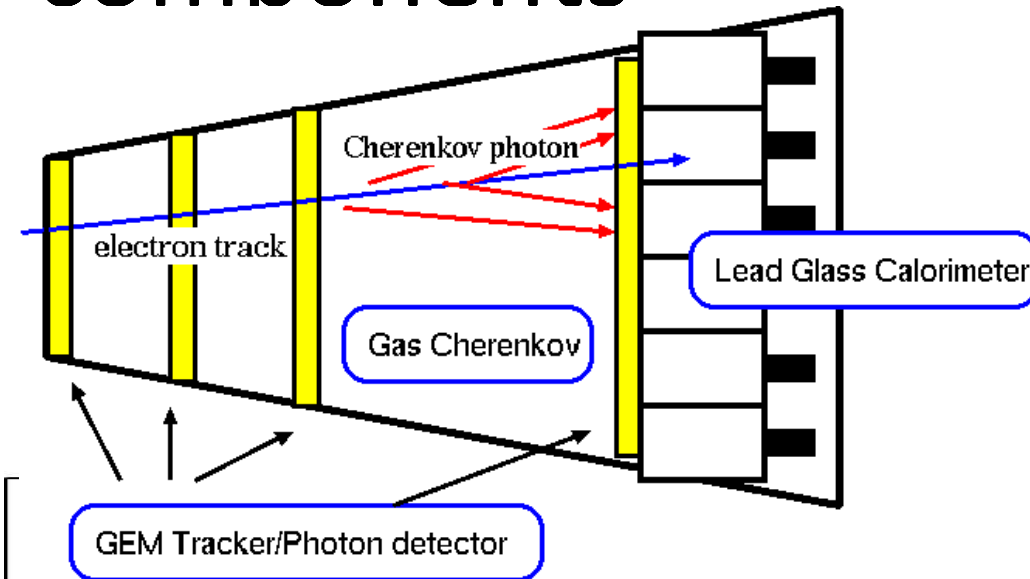
~Position resolution 100μm

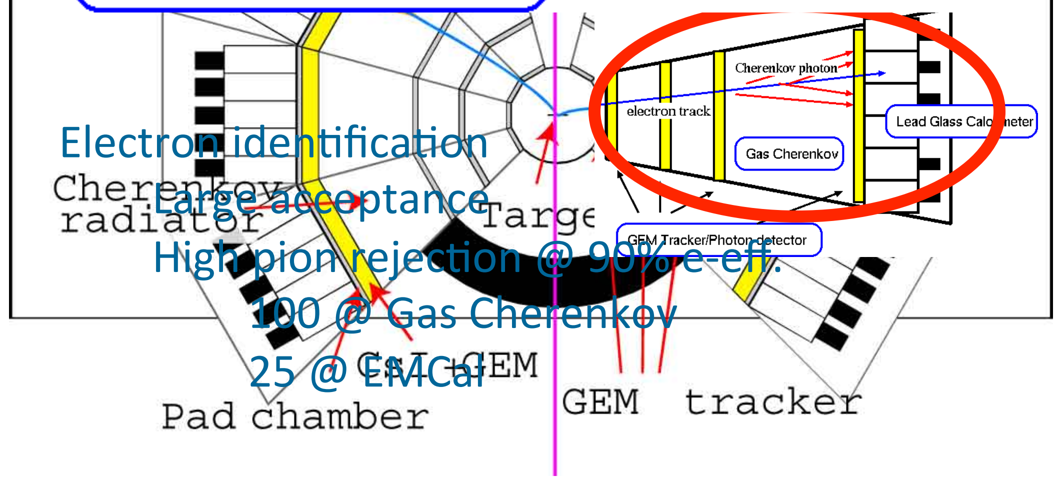
High Rate(5kHz/mm^2)

Small radiation length

(~0.1% per 1 chamber)







Electron identification

Large acceptance

High pion rejection @ 90% e-eff.

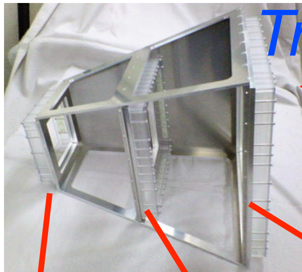
100 @ Gas Cherenkov

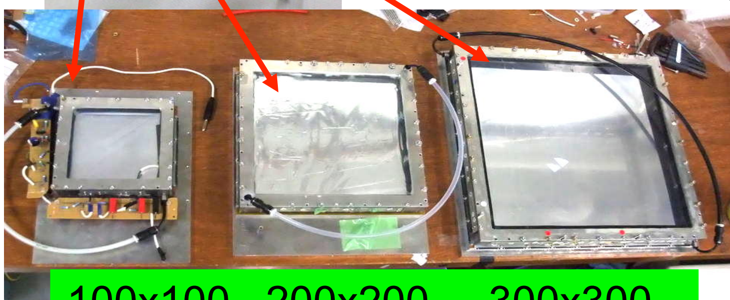
25 @ EMCal

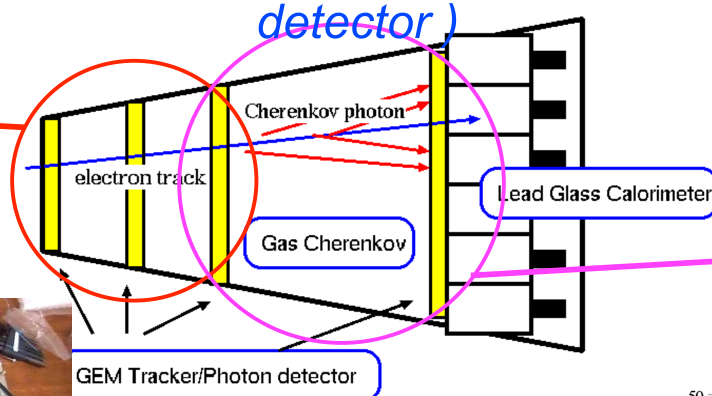
Beam test results of prototype detectors (2012)

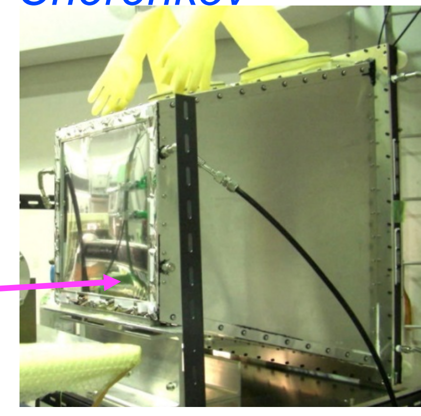
GEM Tracker

HBD (Hadron-Blind Cherenkov detector)



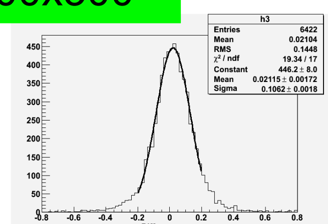




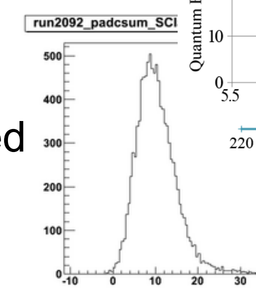


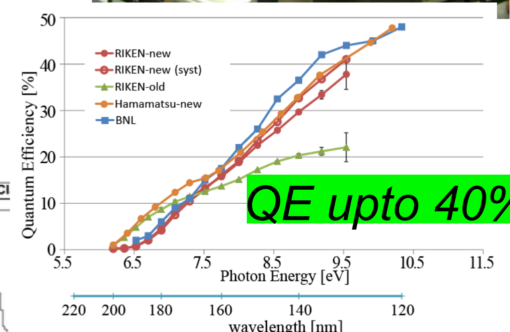
100x100 200x200 300x300

Required position resolution (~100μm) is achieved



UV Cherenkov photons are detected with CsI-evaporated LCP-GEM and CF_4 gas





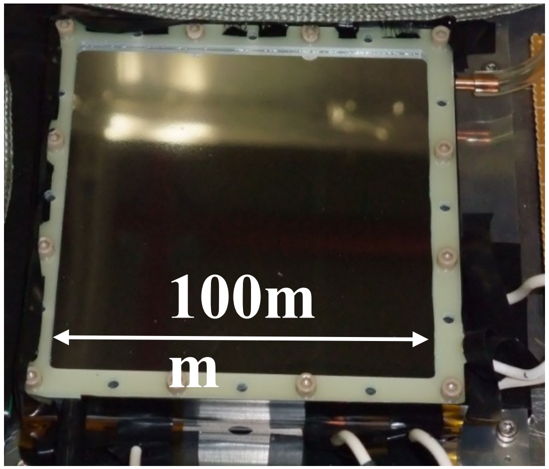
QE upto 40%

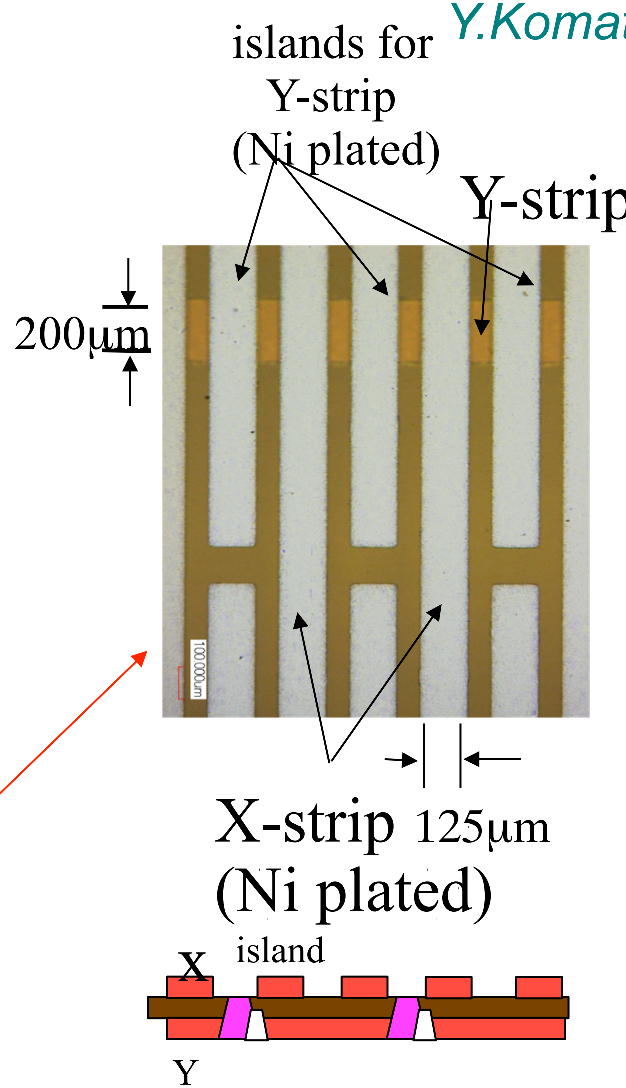
10 p.e.

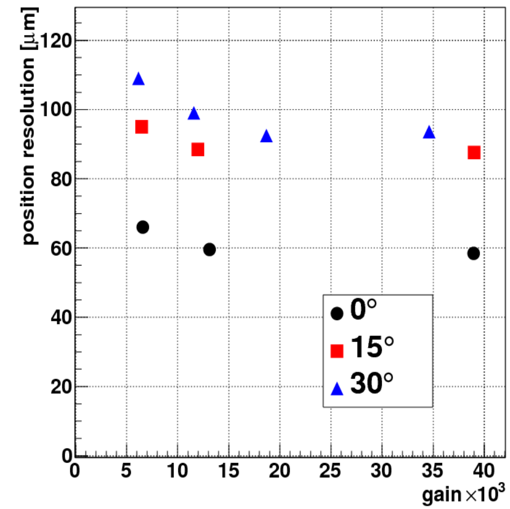
- Large size (300x300mm) PI- and LCP-GEM are successfully worked for a electron beam
  - Stability and response for a pion beam should be checked at J-PARC.
- GEM Tracker is successfully worked.
- Improvement of the photo-detection efficiency of HBD is on going.

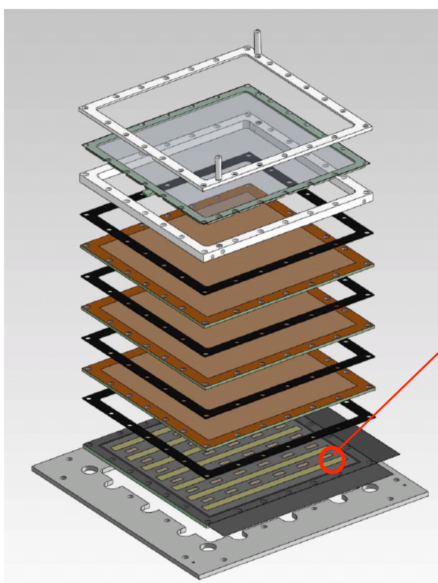
GEM Tracker : first prod. type is tested

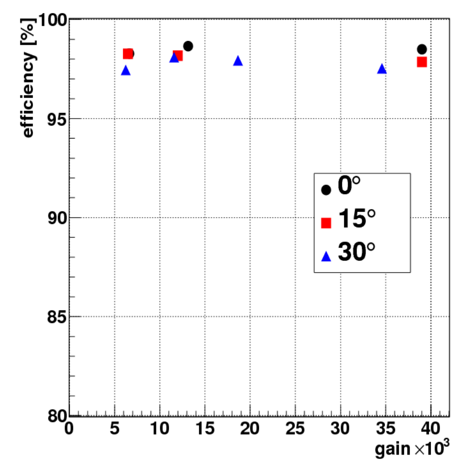
Y.Komatsu, NIM A 732(2013)241





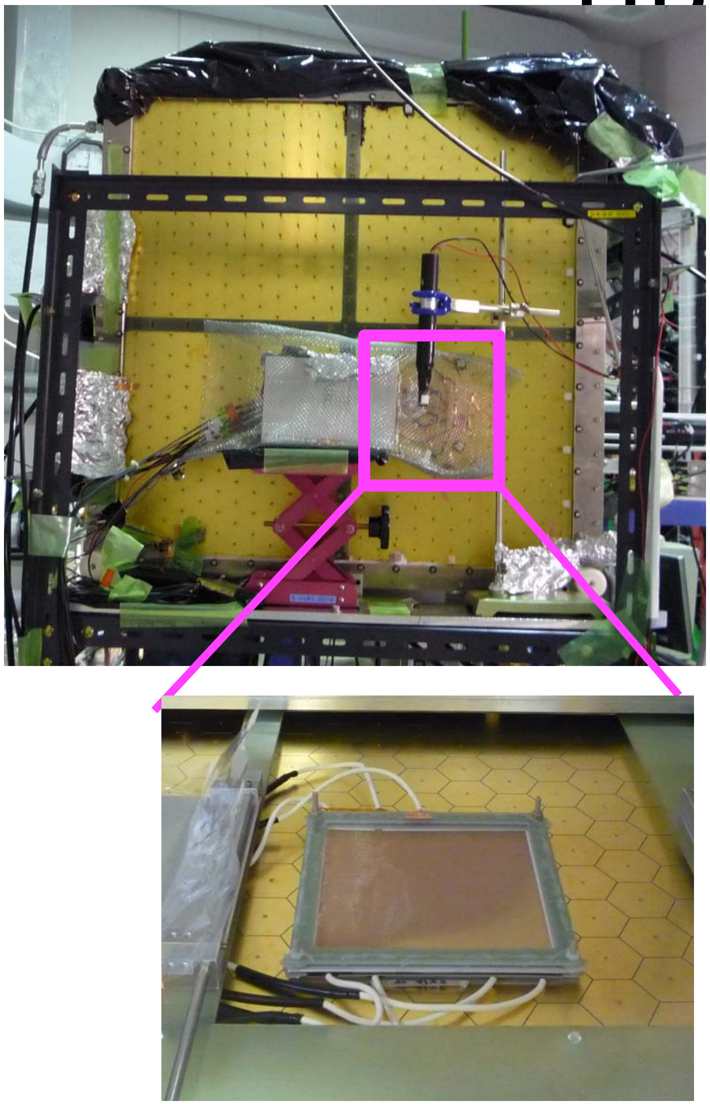


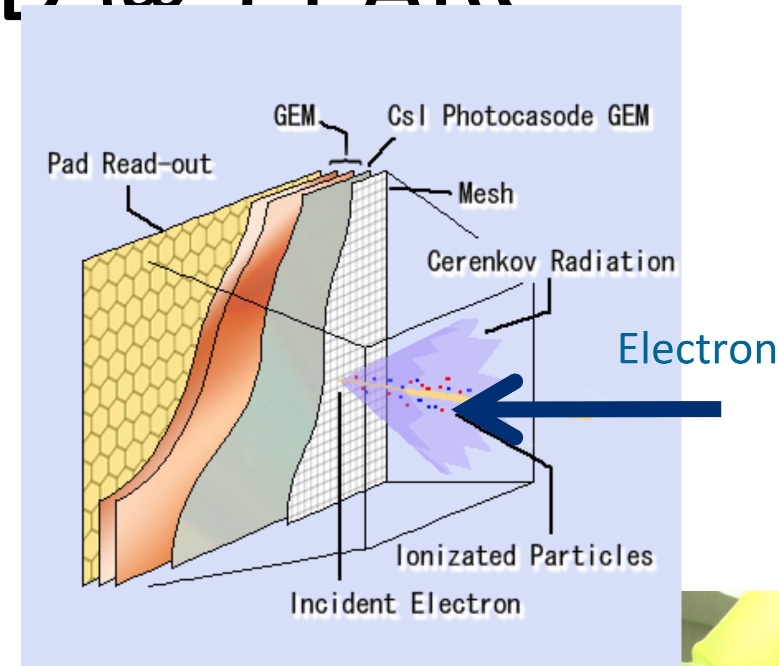


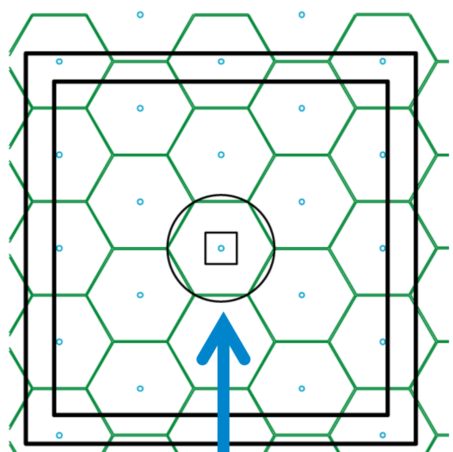


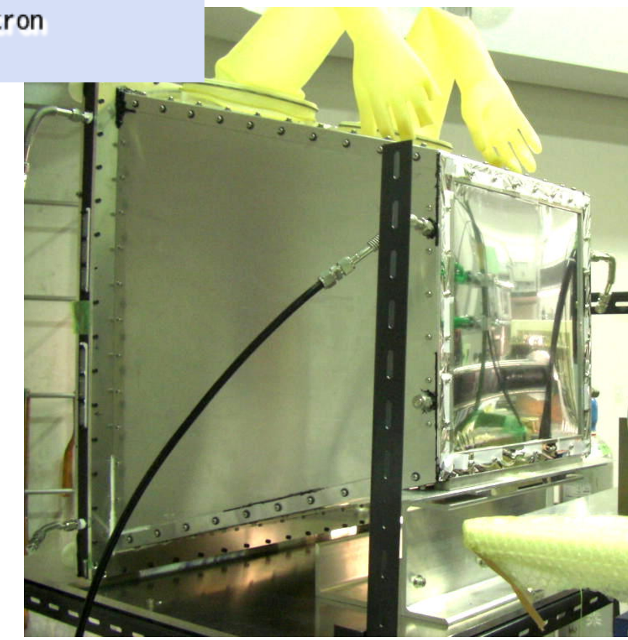
BVH type 2D R/O PCB

HBD @ J-PARC









Cerenkov blob, ϕ~34mm

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.