Hadron Physics at J-PARC

Hiroaki Ohnishi
RIKEN
Nishina Center

Goal for hadron physics at J-PARC

We believed hadron itself will be good experimental laboratory for QCD at Low energy

Chiral symmetry
- hidden symmetry
Hadron mass

Color symmetry
- gauge symmetry
Color confinement

Symmetry of QCD

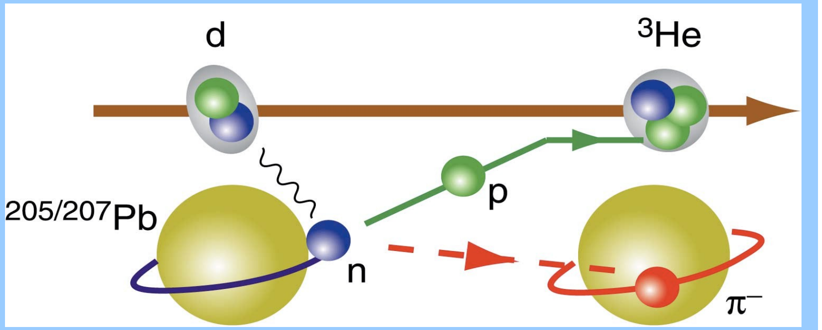
meson in nuclei

Exotic hadron
Hadron spectra

Meson in nuclei

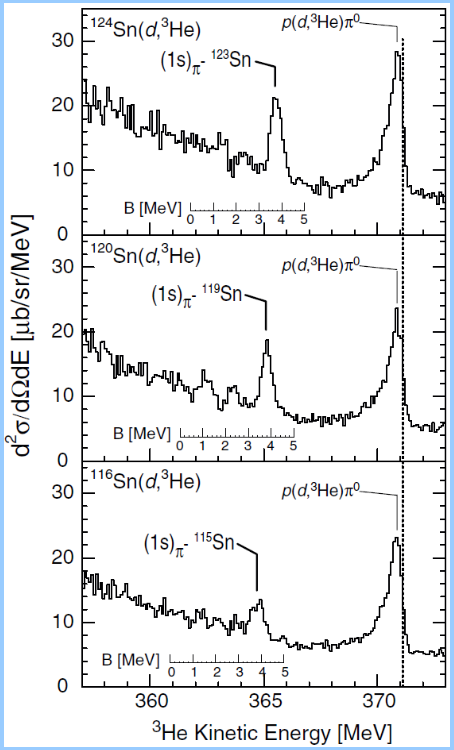
- Probably most successive study for meson in nuclei is the study of pionnic atom.

Pionic-atom

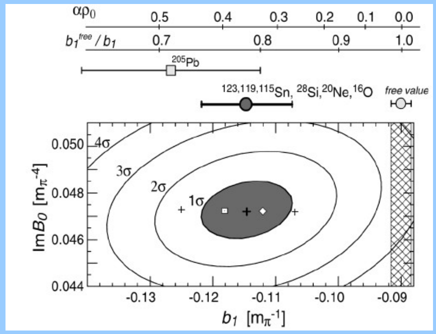


Interaction between Meson and nuclei

Quark condensate $\langle \bar{q}q \rangle$



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



$$\frac{\langle \bar{q}q \rangle_\rho}{\langle \bar{q}q \rangle_0} \approx 1 - \frac{\sigma_N}{m_\pi^2 f_\pi^2} \rho,$$

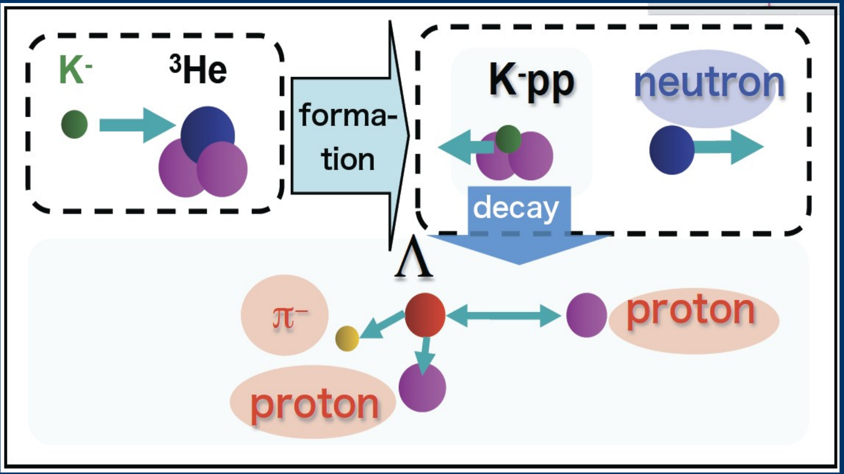
$$R(\rho) = \frac{b_1^{\text{free}}}{b_1^*(\rho)} \approx \frac{f_\pi^*(\rho)^2}{f_\pi^2} \approx 1 - \alpha\rho.$$

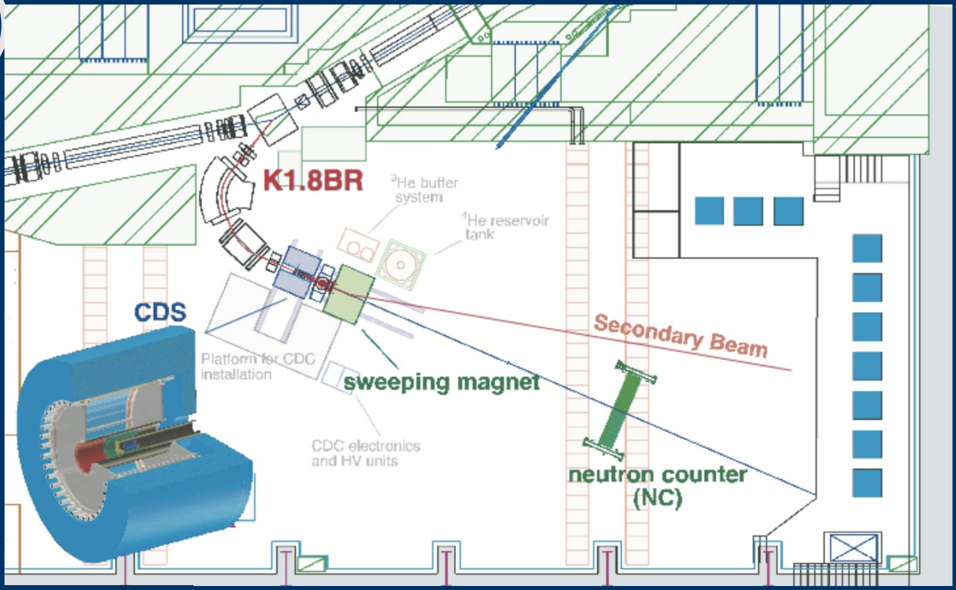
Systematic study of dynamical chiral symmetry breaking and partial restoration

- Mesic-nuclei factory (meson-nucleus bound state!)
  - Strangeness in nuclei
    - K aonic Nucleus (K-pp...) J-PARC E15/E27
    - double Kaonic nucleus(K-K-pp) J-PARC LoI
  - Vector meson in nuclei
    - ω-mesic nucleus J-PARC E26
    - Φ-mesin nucleus J-PARC E29
  - Chiral symmetry of baryon : nucleon-N(1535)
    - η-mesic nucleus J-PARC LoI
  - $U_A(1)$ amonaly
    - η'-mesic nucleus

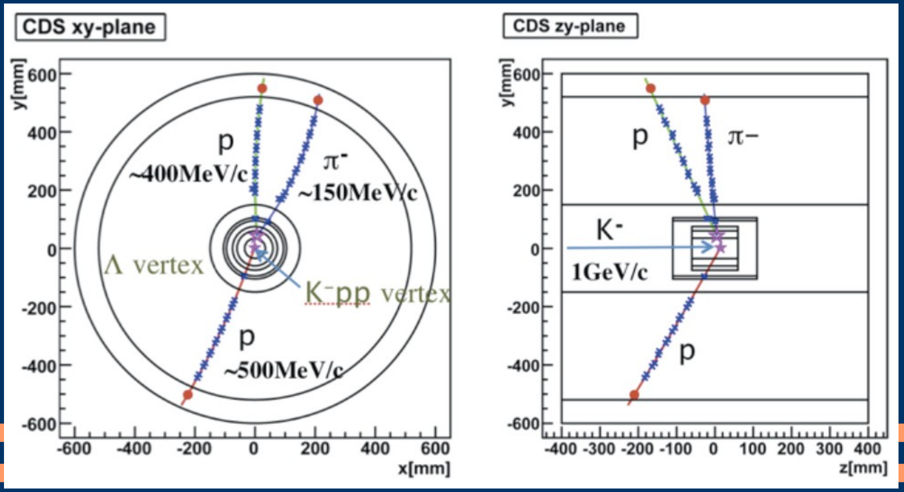
Search for Kaonic nuclei K-pp bound state

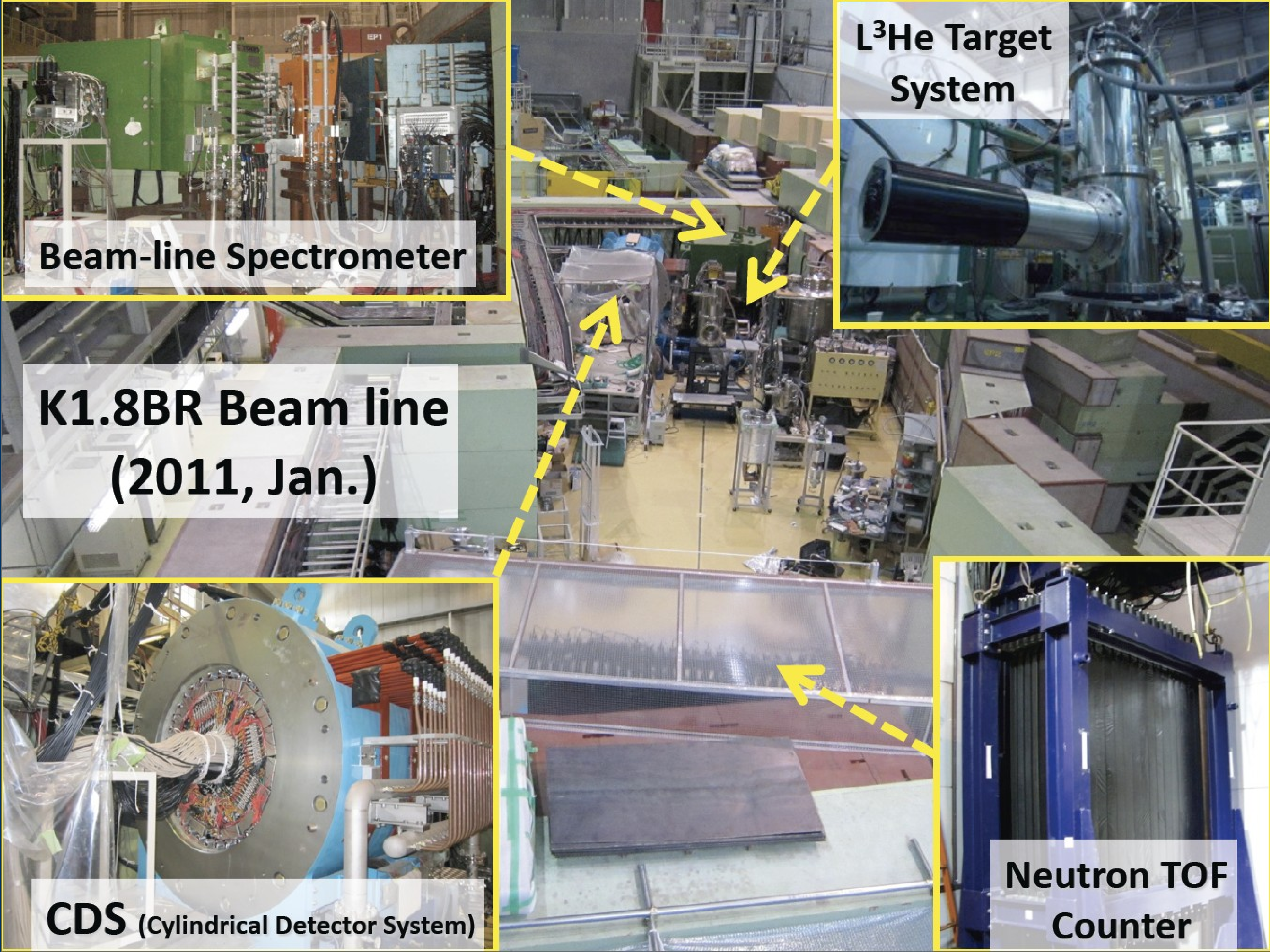
- J-PARC E15: $^3He(K^-,n)$
  M. Iwasaki RIKEN et al.
  K^-3He → "ppK^-" + n
  using 1 GeV/c K^-





Missing mass (using neutron)
Invariant mass reconstruction (Λ+p)
Full kinematics reconstruction
formation & decay





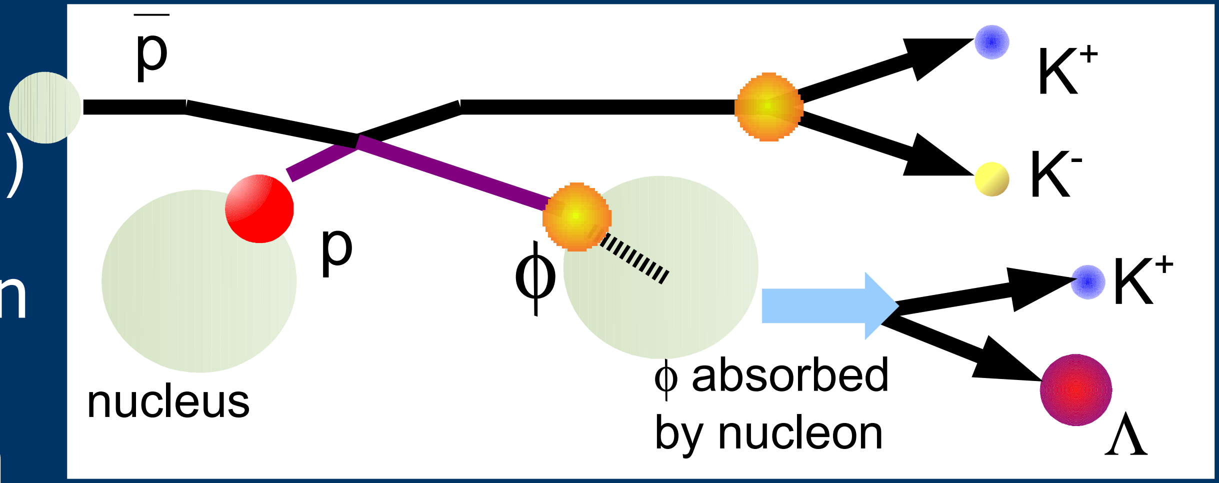
Beam-line Spectrometer
L^{3}He Target System
K1.8BR Beam line (2011, Jan.)
CDS (Cylindrical Detector System)
Neutron TOF Counter

Search for ϕ meson bound state

J-PARC E29
(H. Ohnishi,RIKEN et al.)

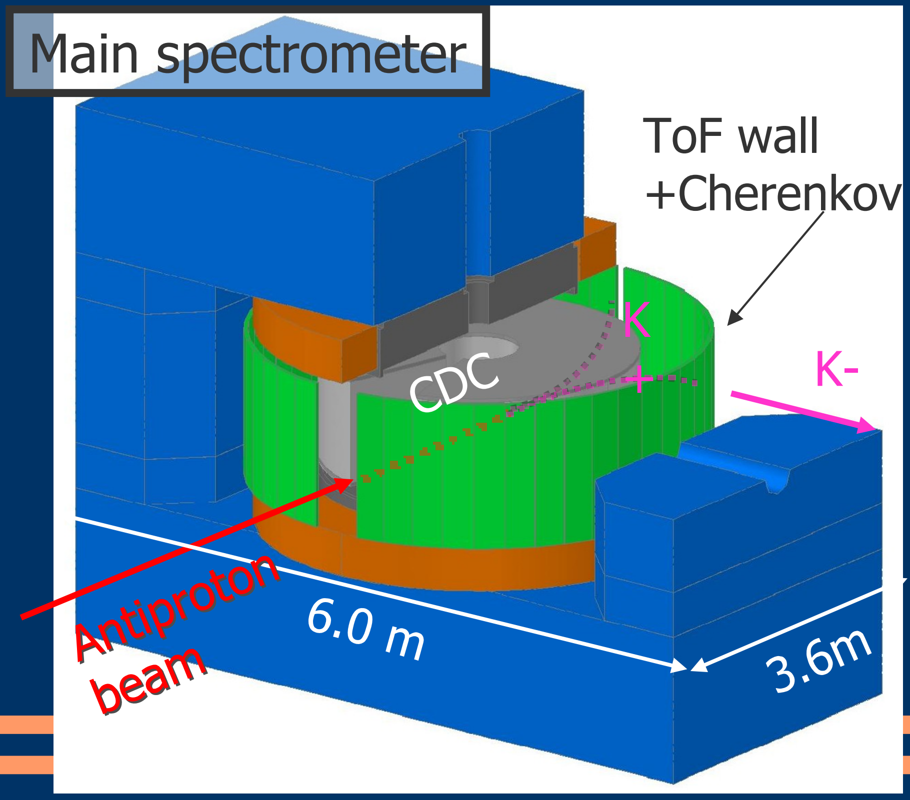
Using p($\bar{p}$,ϕ)ϕ reaction

antiproton beam with
1.0 – 1.1 GeV/c



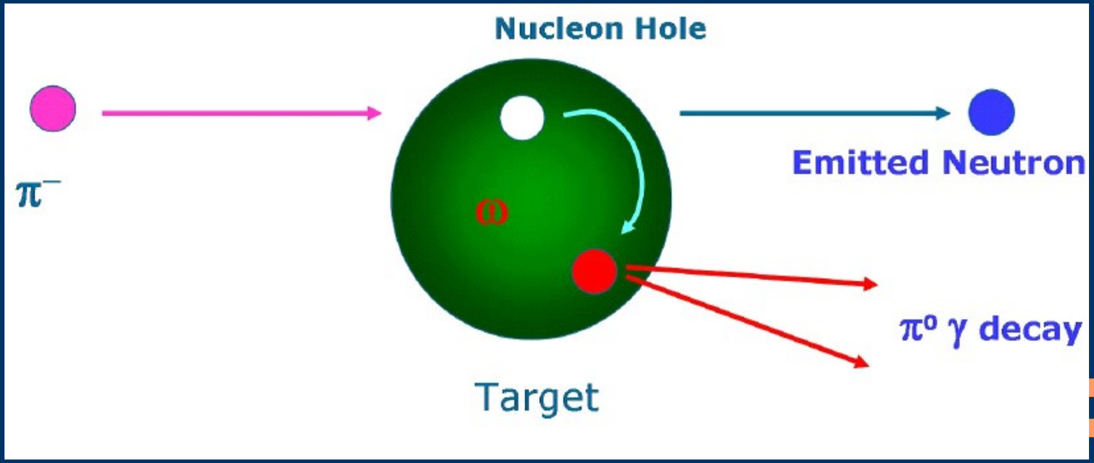
Large acceptance for
forward going ϕ meson
(for missing mass analysis)

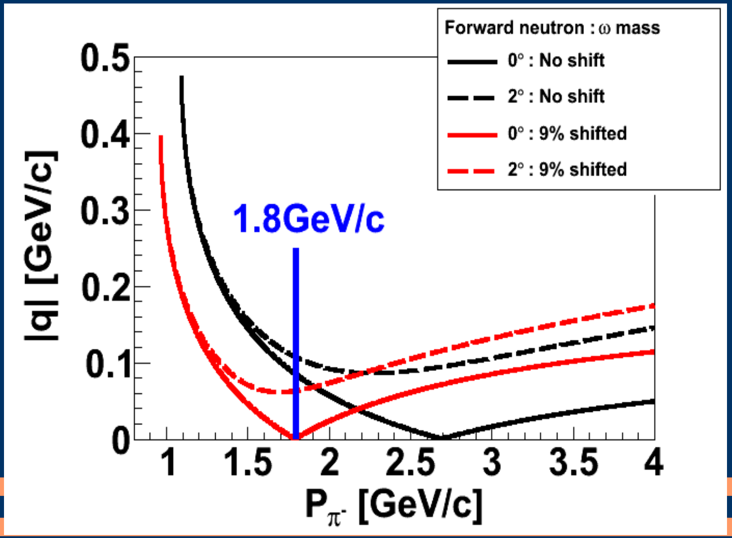
Large solid angle for the
decay particles, K^+ / Λ,
from ϕ mesic nucleus



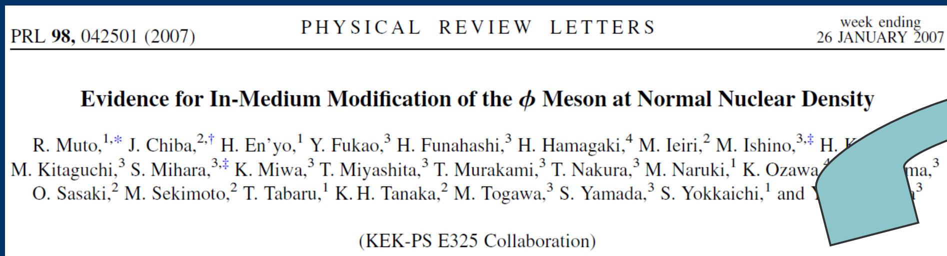
ω meson in nucleus

- J-PARC E26 experiment (K. Ozawa,KEK et al.)
- Producing w meson using (π^-,n) reaction
- ω meson will be produce
  at rest (zero momentum respect to nucleus)
  to choosing incident pion momentum
- ω line shape in nucleus evaluated
  via $\pi^0 \gamma$ decay channel of ω





ϕ mesons in normal nuclear media

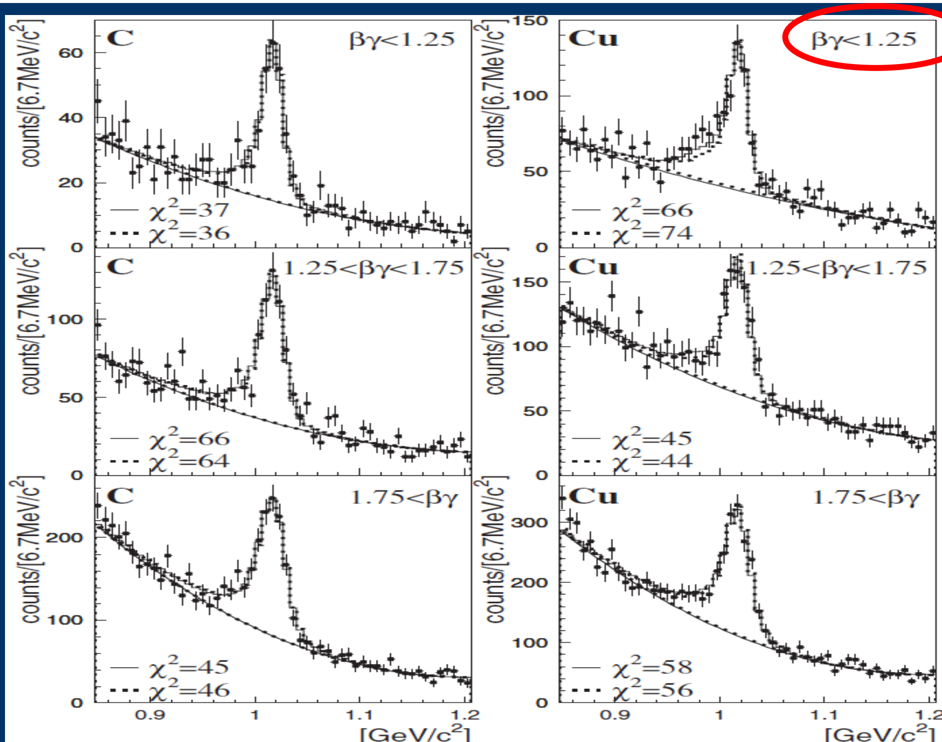


PRL **98,** 042501 (2007) PHYSICAL REVIEW LETTERS week ending 26 JANUARY 2007

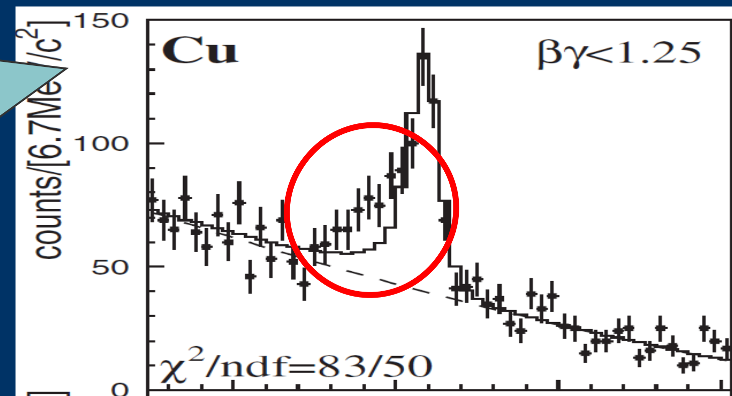
Evidence for In-Medium Modification of the ϕ Meson at Normal Nuclear Density

R. Muto,[1,*] J. Chiba,[2,†] H. En'yo,[1] Y. Fukao,[3] H. Funahashi,[3] H. Hamagaki,[4] M. Ieiri,[2] M. Ishino,[3,‡] H. K
M. Kitaguchi,[3] S. Mihara,[3,‡] K. Miwa,[3] T. Miyashita,[3] T. Murakami,[3] T. Nakura,[3] M. Naruki,[1] K. Ozawa ma,[3]
O. Sasaki,[2] M. Sekimoto,[2] T. Tabaru,[1] K. H. Tanaka,[2] M. Togawa,[3] S. Yamada,[3] S. Yokkaichi,[1] and

(KEK-PS E325 Collaboration)



PRL **98,** 042501 (2007)



- Invariant mass spectra for ϕ meson in heavy nucleus shows
  - 3.4% mass shift
  - 3.6 times width broadening

when only the slowly moving phi mesons with respect to the target nuclei were selected ($\beta\gamma_\phi$<1.25)

δm_ϕ = -35 MeV @ $\rho=\rho_0$

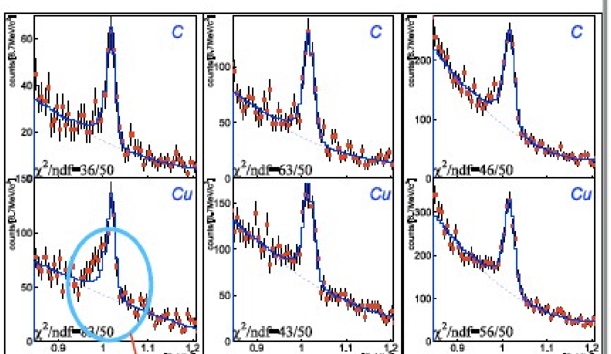
J-PARC E16
High statistics
Systematic study

S. Yokkaichi

• J-PARC E16 experiment

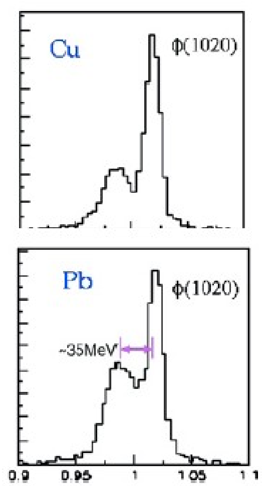
- Measure the vector-meson mass modification in nuclei systematically with the e^+e^- invariant mass spectrum
- Explore the origin of hadron mass due to the breaking of chiral symmetry proposed by Nambu
- A 30 GeV primary proton beam (10^{10} /spill) / 5 weeks of physics run to collect ~10^5 $\phi \rightarrow e^+e^-$ for each target

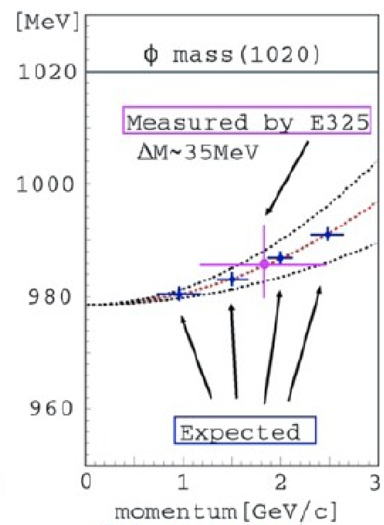
Precedent exp. (KEK-PS E325)



ϕ–mass is modified in large nuclei for slowly moving mesons ... consistent with the prediction based on the QCD sum rule

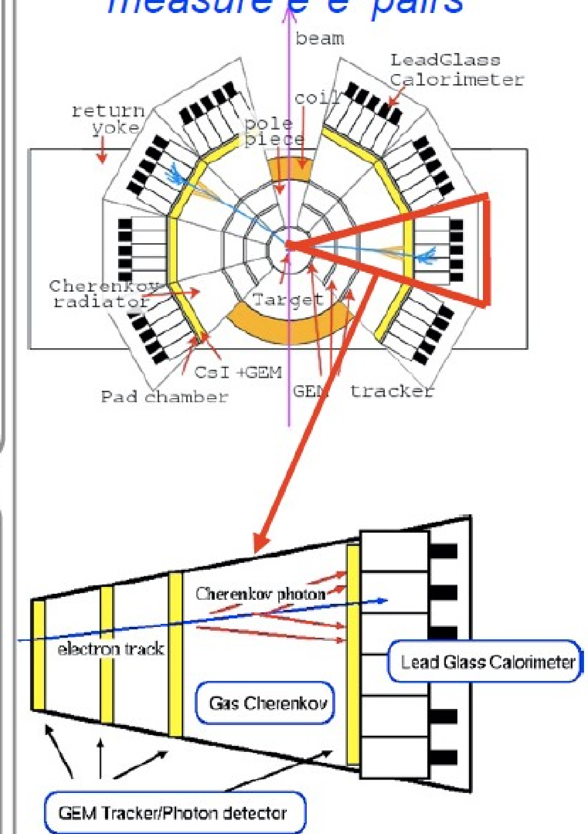
Proposed exp. E16





Nuclear size dependence & *Momentum dependence* of mass modification

New Spectrometer to measure e^+e^- pairs



modular type detectors : GEM Tracker, HBD (GC) & EMC for the electron ID and tracking

- Prototype detector is tested with electron beam

Goal for hadron physics at J-PARC

We believed hadron itself will be good experimental laboratory for QCD at Low energy

Chiral symmetry
- hidden symmetry
Hadron mass

Color symmetry
- gauge symmetry
Color confinement

Symmetry of QCD

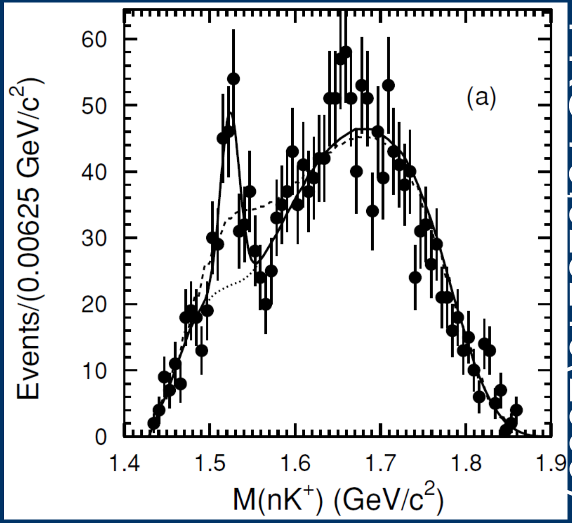
Hadron in nuclei

Exotic hadron
Hadron spectra

Search for exotic hadron

- Penta-quark state???
  - Penta quark state is not forbidden in QCD
  - But... why only a few candidates are observed?
  - What is the mechanism to forming hadrons
    - How dose color confinement works?

Spring-8 : LEPS



PRC 79,025210(2009)

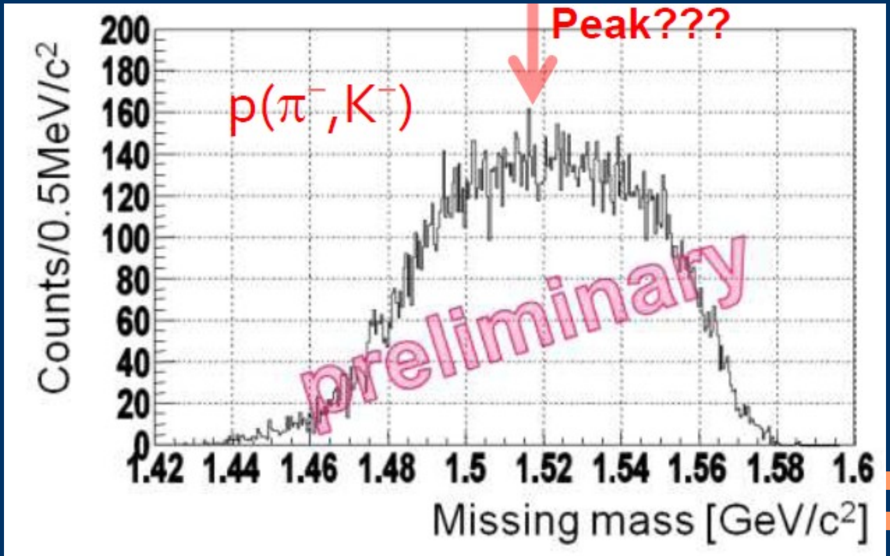
$\gamma d \rightarrow K^+K^-pn$

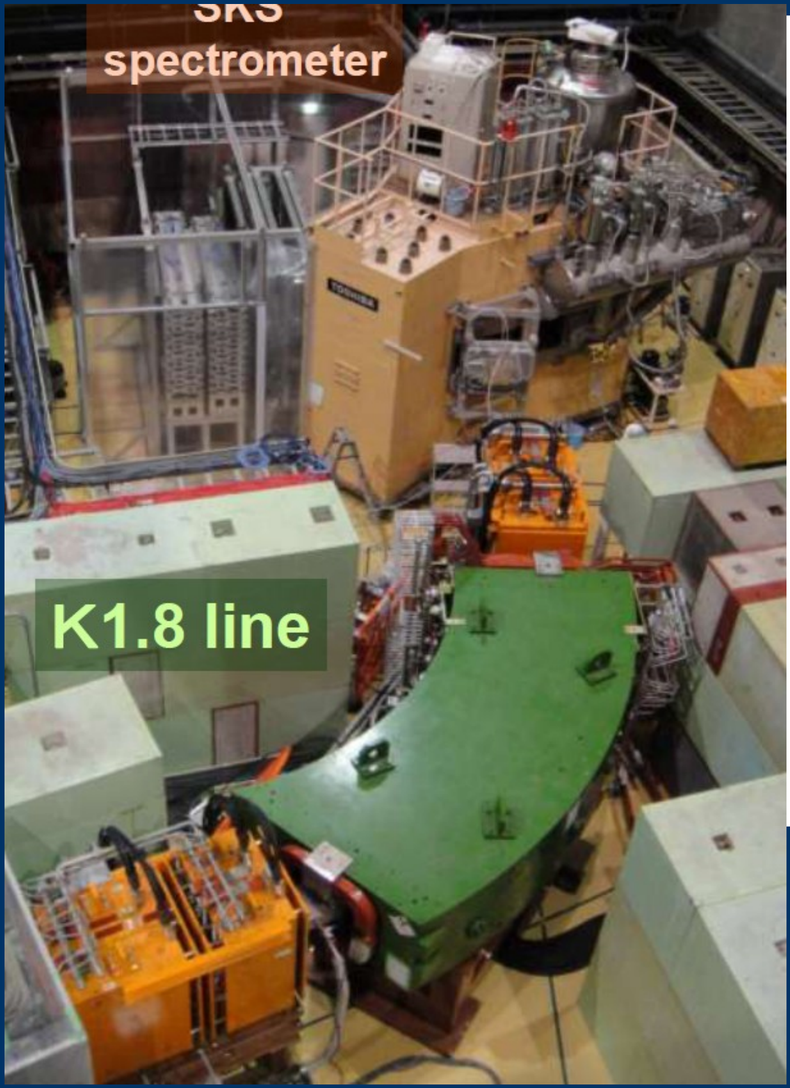
Very narrow width ~ 1 MeV

Negative results from High energy

Search for penta-quark at J-PARC

- J-PARC E19 experiment (M. Naruki/KEK et al.)
- Pentaquark formation using (π,K) reaction
  $\pi^- + p \rightarrow K^- + X$
- Signal identified with missing mass spectroscopy using out going K^-

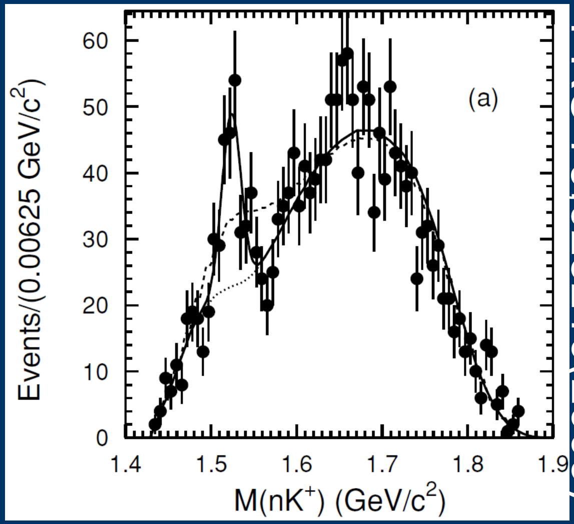




Search for exotic hadron

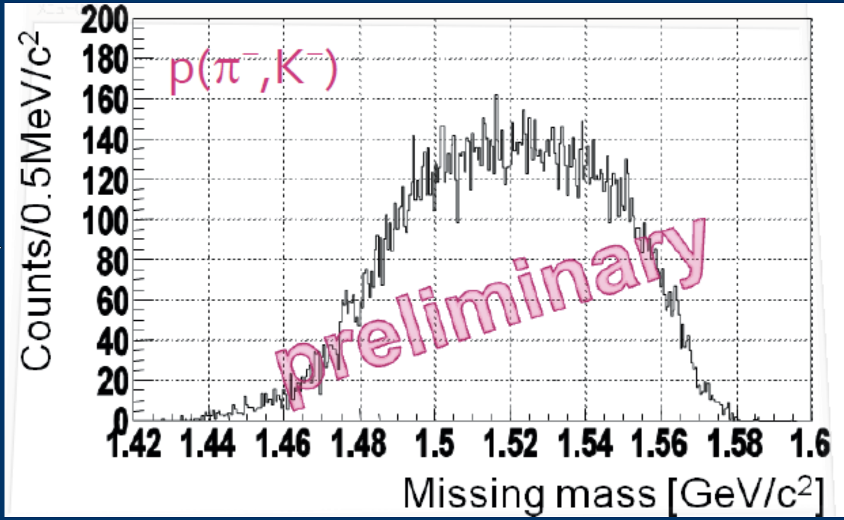
- Penta-quark state???
  - Penta quark state is not forbidden in QCD
  - But... why only a few candidates are observed?
  - What is the mechanism to forming hadrons
    - How dose color confinement works?

Spring-8 : LEPS



PRC 79,025210(2009)

J-PARC : E19



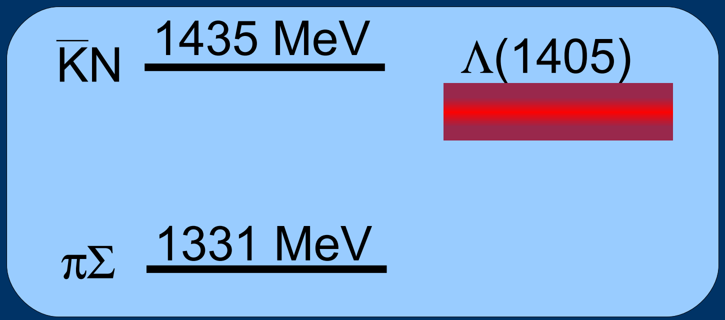
$\gamma d \rightarrow K^+K^-pn$

p(π^-,K$^-$)

Direct Θ^+ production experiment : $K^+ + n \rightarrow \Theta^+ \rightarrow K^0_s p$ (J-PARC LOI)

Exotic hadron?

- Λ(1405) :
  - The lightest excited baryon with $J^P=1/2^-$
  - Mass : 1406.5±4.0 MeV
    (just bellow $\bar{K}N$ threshold)
  - Width : 50±2 MeV
  - Decay : 100 % $\Sigma\pi$

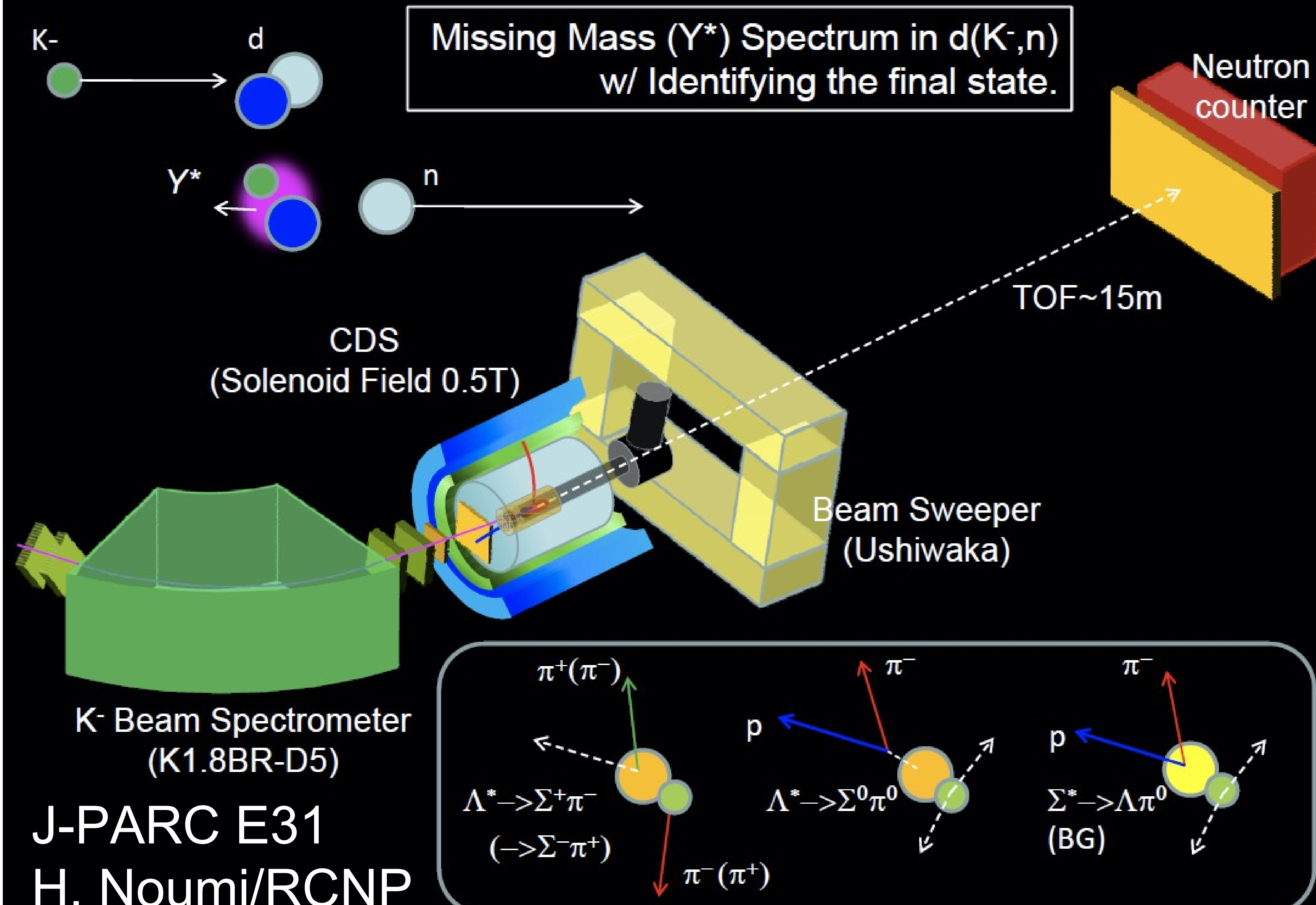


  - normal baryon or $\bar{K}N$ bound state or penta?

Nature of Λ(1405) need to be understood

→ Strongly couple to the $\bar{K}N$ interaction

Λ(1405) Spectroscopy via the (K⁻,n) reaction on Deuteron



J-PARC E31
H. Noumi/RCNP

Future direction of Hadron physics at J-PARC

Goal for hadron physics at J-PARC

We believed hadron itself will be good experimental laboratory for QCD at Low energy

Chiral symmetry
- hidden symmetry
Hadron mass

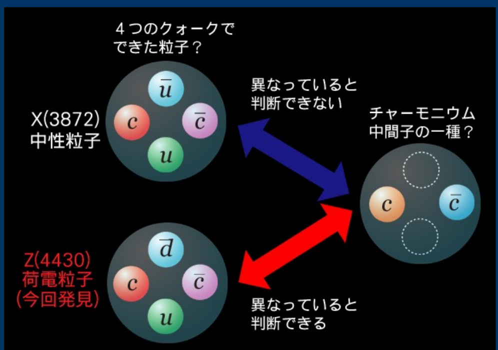
Color symmetry
- gauge symmetry
Color confinement

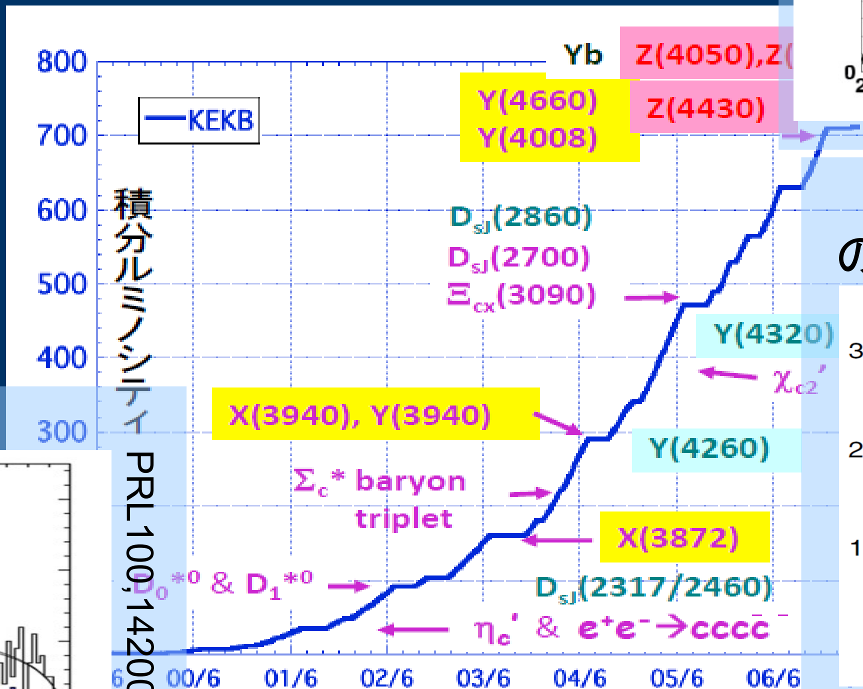
Symmetry of QCD

What is missing subject?

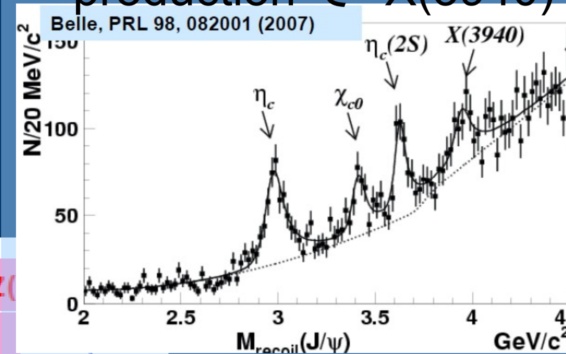
New direction?

- New exotic states recently found at Belle/BaBar/BES....

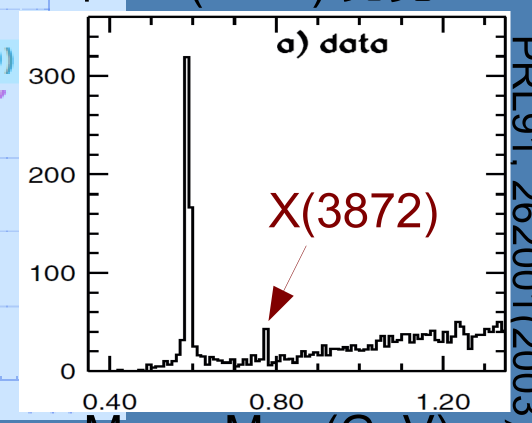




Double charmonium production で X(3940)

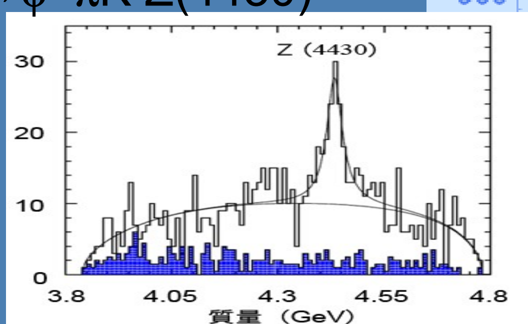


B →J/ψ π+π- K 崩壊の中にX(3872) 発見



$M_{J/\psi\pi\pi}$-$M_{J/\psi}$ (GeV)

B →ψ' πK Z(4430)



Tetraquark candidate with charm quark has been discovered!!

Hadron with charm quark may open new door to hadron physics at J-PARC

Goal for hadron physics at J-PARC

We believed hadron itself will be good
experimental laboratory for
QCD at Low energy

Chiral symmetry
- hidden symmetry
Hadron mass

Color symmetry
- gauge symmetry
Color confinement

Symmetry of QCD

Hadron with heavy Flavor
strangeness → charm

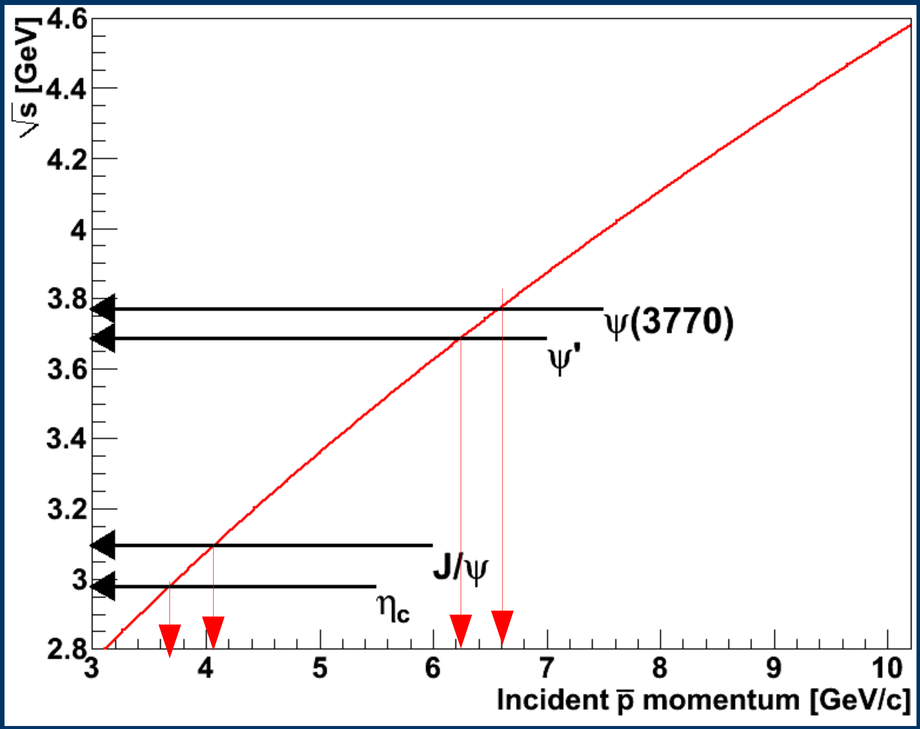
Shopping list for future!

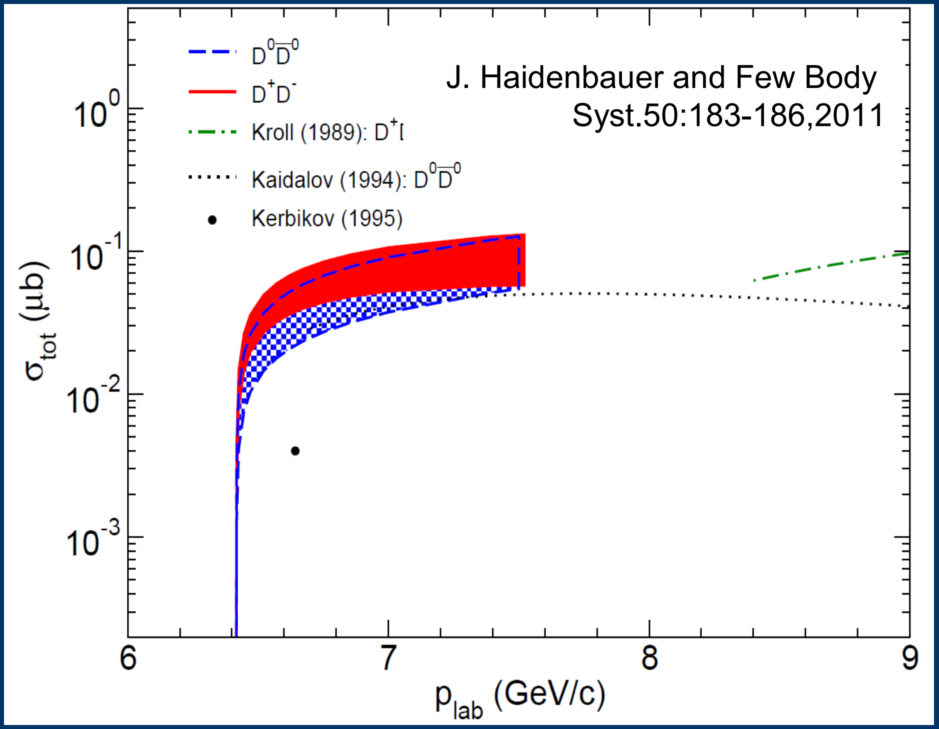
- systematic study of "meson in nuclei"
  → hadron-hadron interaction
  which may lead us to origin of hadron mass
  " chiral symmetry restoration"
- Spectroscopy of
  - S=-1, -2, -3 baryons and even charmed baryons!
    which may give us hints of "confinement"
- High precision hyper nuclei spectroscopy
  - Baryon in nuclear matter?
- Charm physics → reinvestigation SU(3) world
  using charm quark as a probe!

New physics opportunity at J-PARC

Hadron physics with High-p anti-protons

Physics reach using $\bar{p}$





Charmonium Production threshold

$\bar{p}p \rightarrow J/\Psi$ @ 4.05 GeV/c

$\bar{p}p \rightarrow \Psi(3770)$ @ 6.6 GeV/c

$\bar{p}p \rightarrow X(3872)$ @ 7.0 GeV/c

Problem is its small cross section

Open charm cross section

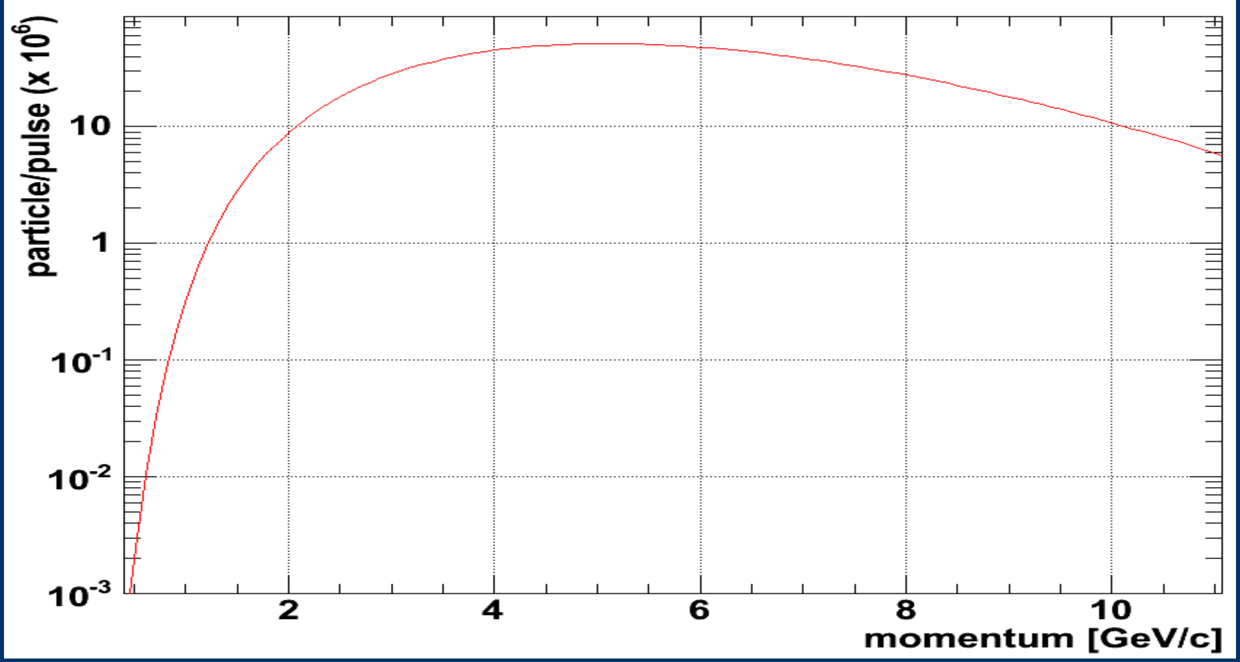
$\bar{p}p \rightarrow D^0\bar{D}^0$ @ 6.4 GeV/c

$\sigma_{D\bar{D}} \sim 100$ nb;

p momentum >7 GeV/c

Feasibility?

- How much antiproton beam will be available?
  - J-PARC MR : 270 kW, 30% loss Ni target
  - Acceptance for beam line spectrometer ~ 2msr%



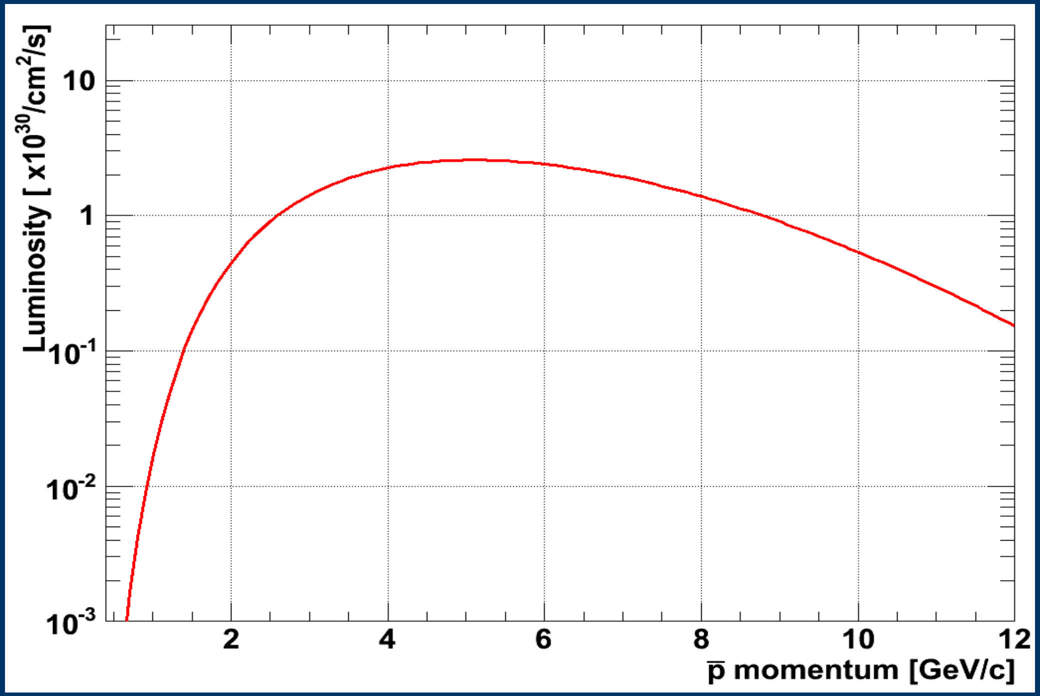
4×10^7 /6s: 4 GeV/c $\bar{p}$

1×10^7 /6s: 10 GeV/c $\bar{p}$

What does this mean?

Luminosity for $\bar{p}$ at J-PARC

- Working assumption
  - 1g/cm^2 liquid Hydrogen target



2x10^{30}/cm^2/s @ 4GeV/c

1x10^{30}/cm^2/s @ 8GeV/c

PANDA

Luminosity$_{Max}$

~10^{32}/cm^2/s

Hadron physics with antiproton beam
is not only possible at PANDA/GSI !
We can do it using antiproton beam at J-PARC!

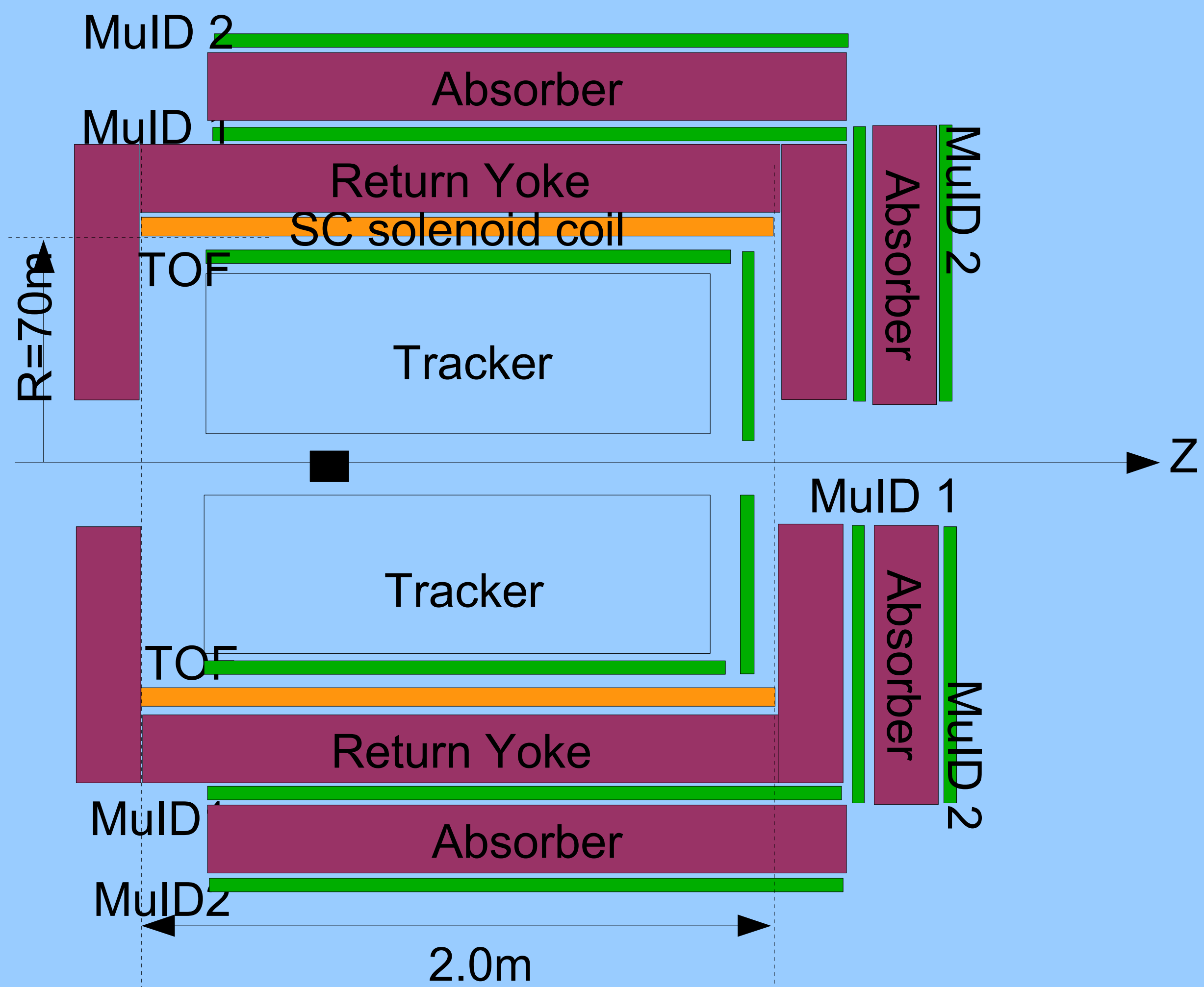
Charmonium production

- Charmonium production cross section at pole (σ_0)
  - $\sigma_{\bar{p}p\to J/\psi\to\mu\mu}$ @4.05 GeV/c ~ 300 nb
  - $\sigma_{\bar{p}p\to\psi'\to\mu\mu}$ @6.6 GeV/c ~ 2.9 nb
  - $\sigma_{\bar{p}p\to X(3872)\to J/\psi\pi\pi}$ @7 GeV/c ~ 13 nb
- Effective cross section
  - $\sigma_{effective} \sim \sigma_0 \times \Gamma_{charmonium} / \Delta E$

    (ΔE : energy spread of the beam)
- Expected ΔE :
  - $dp/p=\pm 1\% \to \Delta E \sim 24$ MeV
- Effective cross section
  - $\sigma_{\bar{p}p\to J/\psi\to\mu\mu}$ ~ 1.2 nb
  - $\sigma_{\bar{\pi}\pi\to\psi'\to\mu\mu}$ ~ 1.6 pb
  - $\sigma_{\bar{p}p\to X(3872)\to J/\psi\pi\pi}$ ~ 1.3 nb (Γ assumed to be 2.3 MeV)

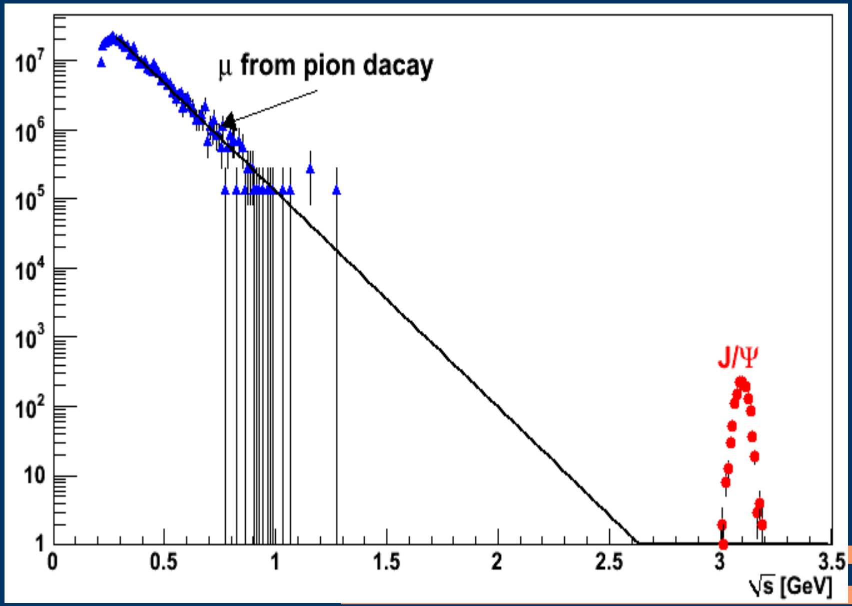
J/Ψ production ?

Muon spectrometer at J-PARC



J/Ψ production ?

- Luminosity ~ 2 μb^{-1}/s
- 1 month ~ $2\text{x}10^6$ s
- Integrated Luminosity ~ 4 pb^{-1}
- Energy spred of the beam dE ~ 23 MeV
- $\sigma_{\bar{p}p\to J/\psi\to\mu\mu}$ @4.05 GeV/c ~ 300 nb
- $\sigma_{effective} = \sigma_{peak} * \Gamma_{\psi}/dE$ ~ 1.2 nb
- 4800. $J/\psi \to \mu\mu$ can be produced in 1 month
- 30 % efficiency+Acc etc $\to$ 1400 $J/\psi \to \mu\mu$ / month



What we can learn?
A-dependence of
production cross section
to investigate J/ψ-N interaction

Charm physics at J-PARC?

- Charmed meson production rate?
  - $J/\psi \rightarrow \mu\mu$ ~ 10^3/month
  - $\Psi' \rightarrow \mu\mu$ ~ 50/ month
  - X(3872) $\longrightarrow J/\psi\pi\pi \rightarrow \mu\mu\pi\pi$ ~ 100/month

  - D mesons,
    - $\bar{D}D$ at 7 GeV/c ~ 480,000 / month

Charmonium-nucleon interaction can be investigate by nuclear mass number dependence of charmonium production

But question is what physics behind!

Comment on PANDA v.s. J-PARC J/ψ production on nuclei

- With storage ring experiment, like PANDA, J/ψ production cross section will be dramatically decreased, because of the fermi momentum of nucleon in nuclei.

- On the other hand, at J-PARC, effect of momentum spread of nucleon in nuclei will be compensate by relatively large momentum spread in beam momentum.

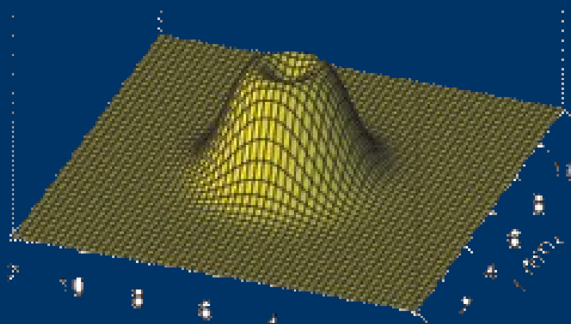
Competitive experiment can be possible!

Any other ideas???

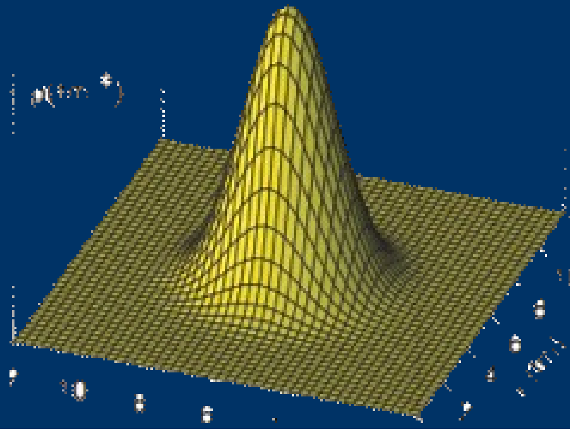
- Nucleus with anti-proton?

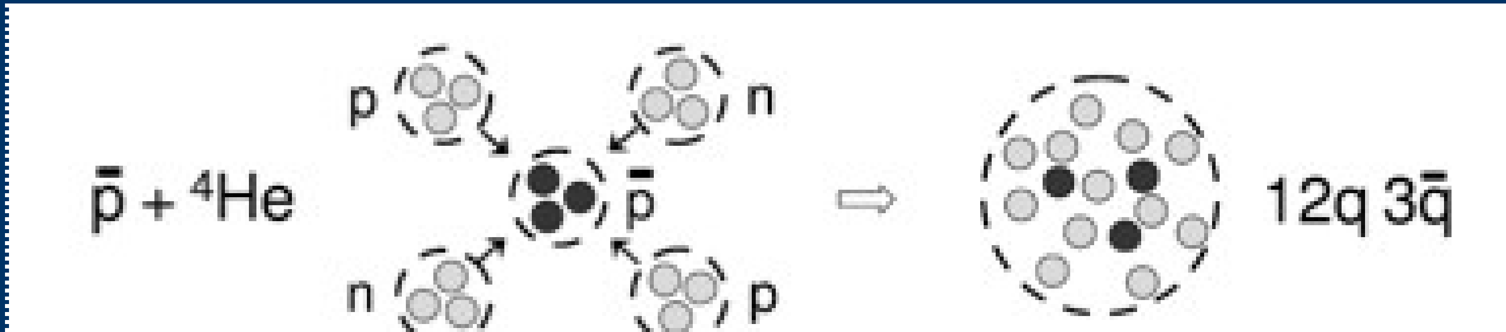
(stealing from Yue Ma(GSI)'s idea)

w/o pbar



w/ pbar





I.N. Mishustin, et al., Phys. Rev. C 71, p.035201, (2005)

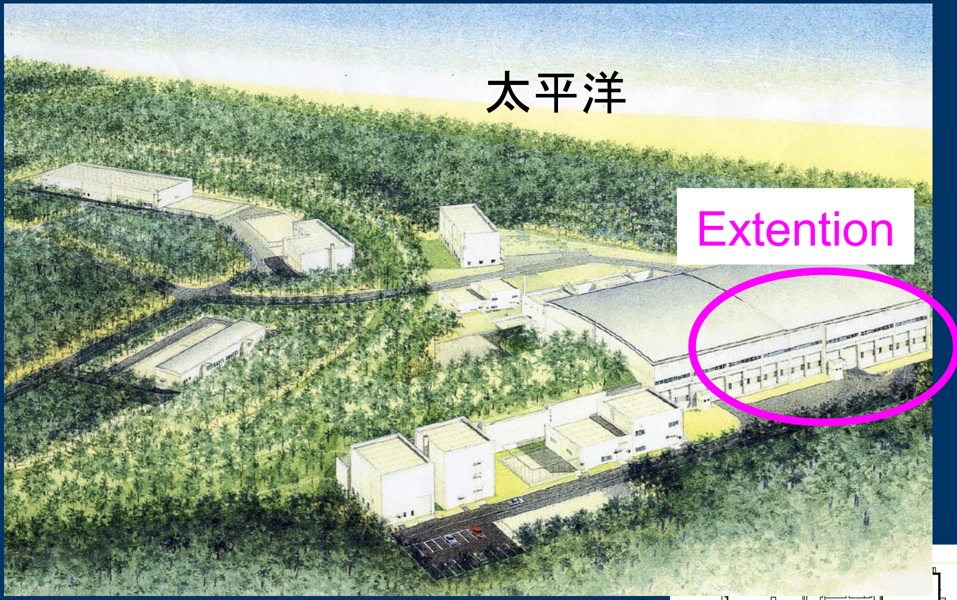
Cold QGP???

However,such high momentum anti-proton is not available at current J-PARC facility

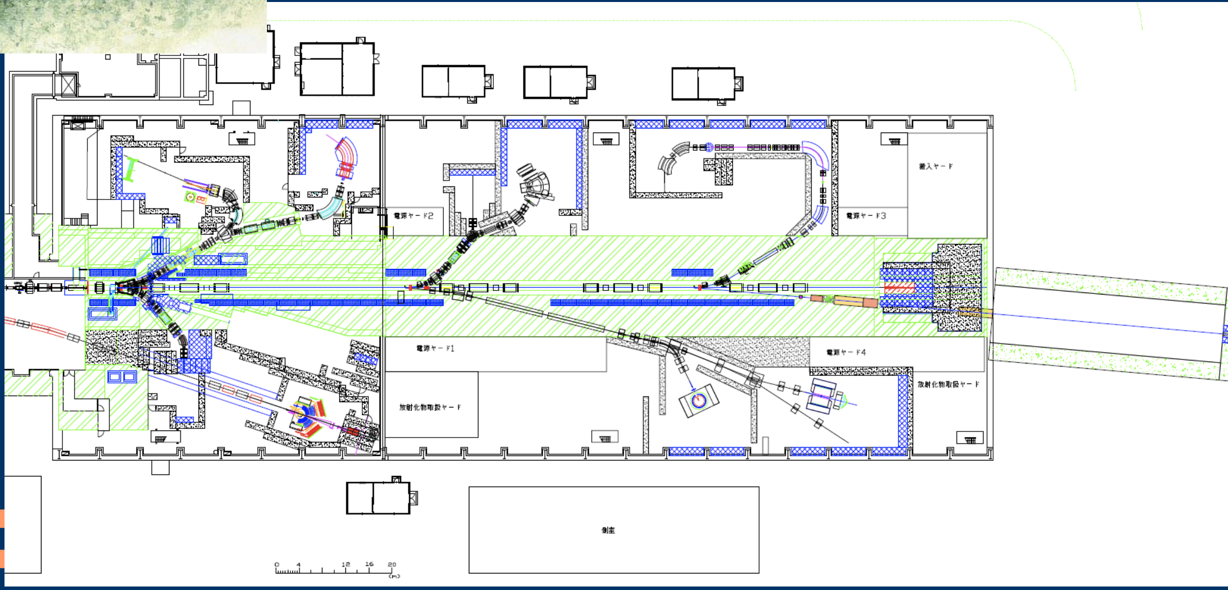
How to realize?

J-PARC hadron hall extension

- RIKEN-JPARC cooperation center project



Extend hadron hall (more than x 2)
Two more production targets
for secandary beam
New beamline, spectrometers



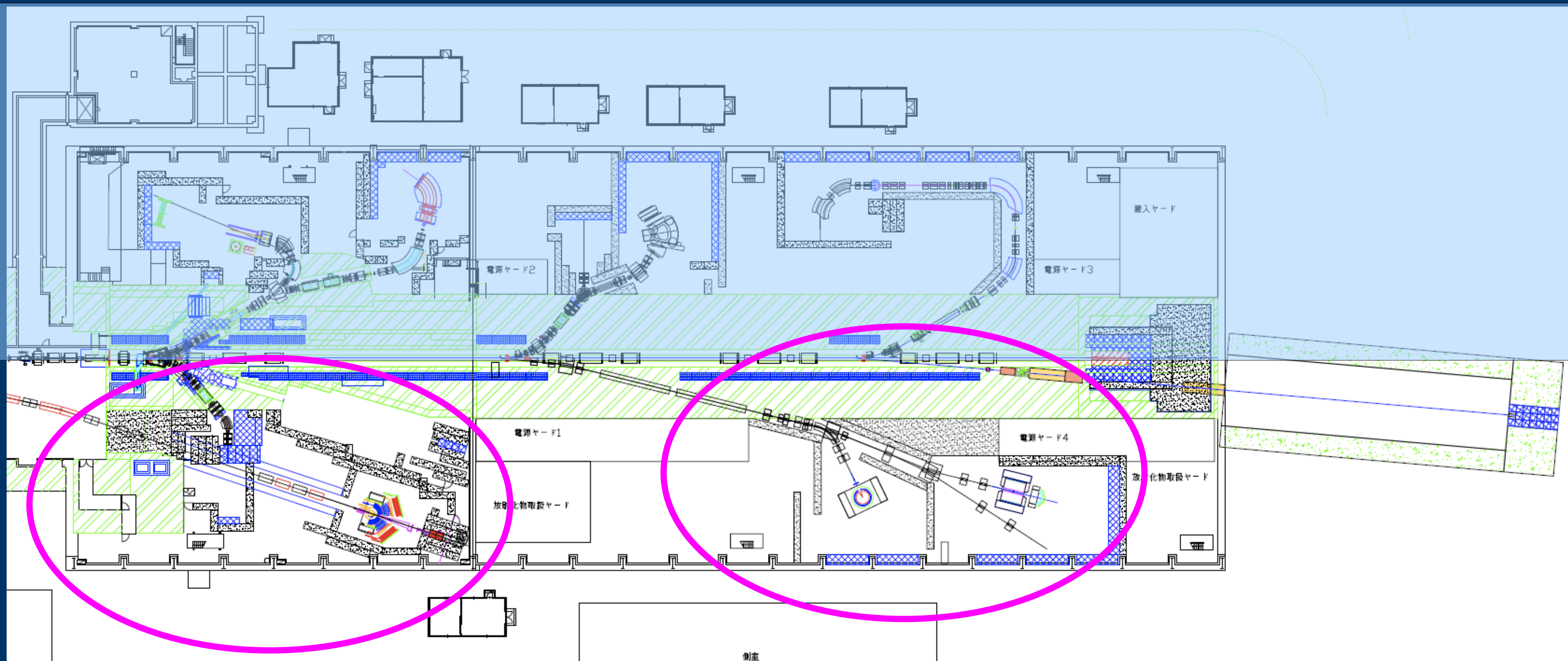
Design started together with nuclear physics community

~ $150 M project

We hope to start 2013

Complete 2017

Extended hadron hall to enhance new physics capability



Charmed baryon spectroscopy
with in 3-4 years

S=-2,-3 Baryon specctroscopy
Charmed meson/baryon in nucleus
with in 5-6 years

Summary

- Physics experiment at J-PARC is now started. New, fresh results will be coming out very soon.
  - E19 : Penta-quark, E15/E27 : K-pp, E31 :L(1405)
- Many other experiments are waiting for the beam!

- Now we are seeking new physics ideas
  - Using high momentum beams, p, K, p, $\bar{p}$
  - Charm physics with anti-proton?
  - More and more!

Your ideas are very welcome!!!

Thank you very much