Hadron physics with high-momentum hadron beams
at J-PARC in 2015
March 13-16, 2015, KEK

Experiments on meson in nuclear matter

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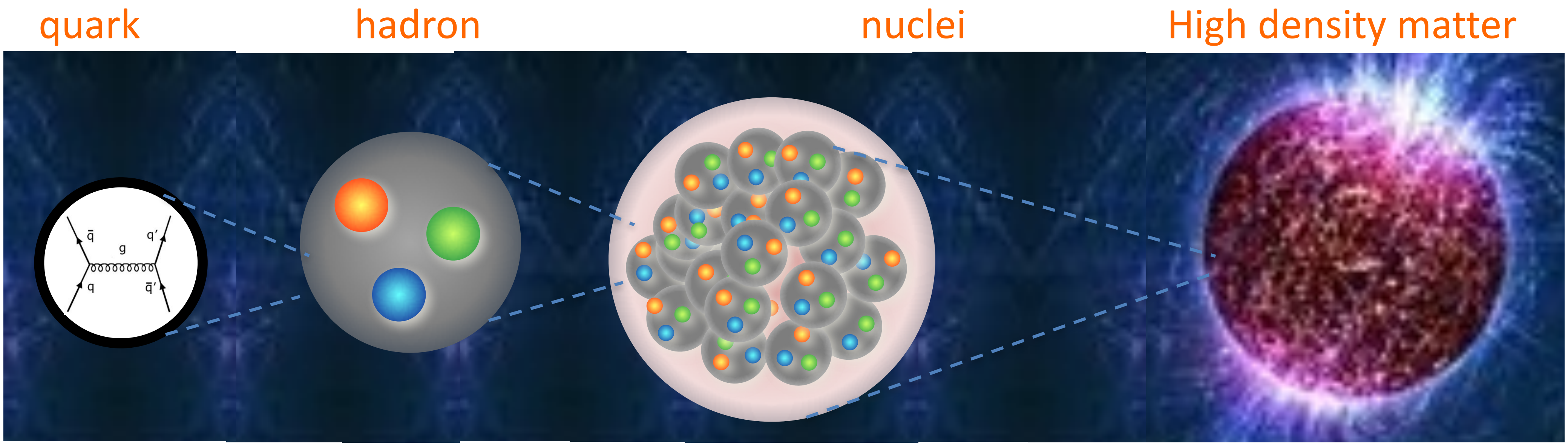
Final goal for the hadron physics

to understand strong interacting matter

quark/hadron/nuclei to high density nuclear matter



How this world created

based on QCD

Key to understand QCD at low energy

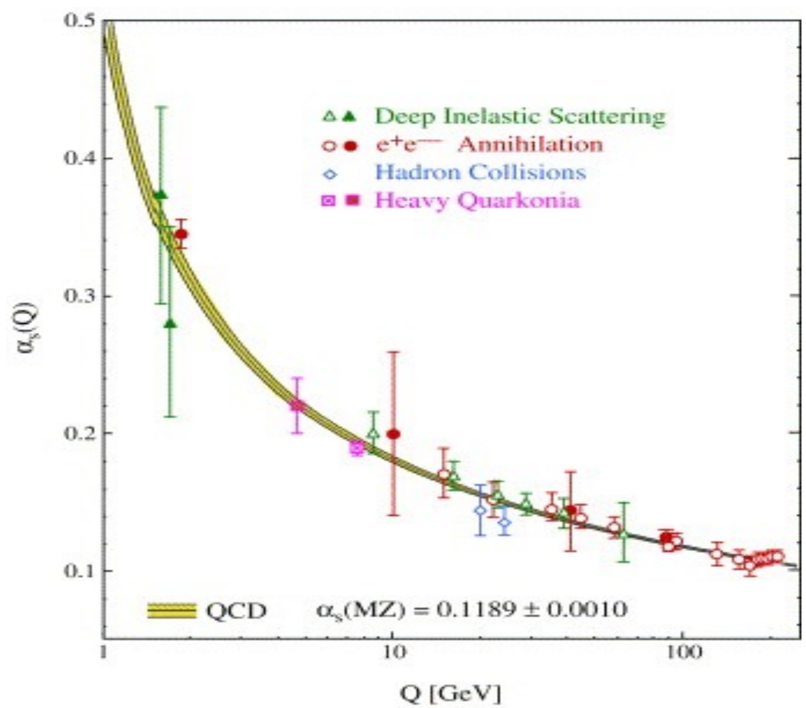
1) Spontaneous breaking of chiral symmetry

2) Confirment

Key for Hadron property
-> mass, structure

Large coupling constant at low energy region

pQCD will not work



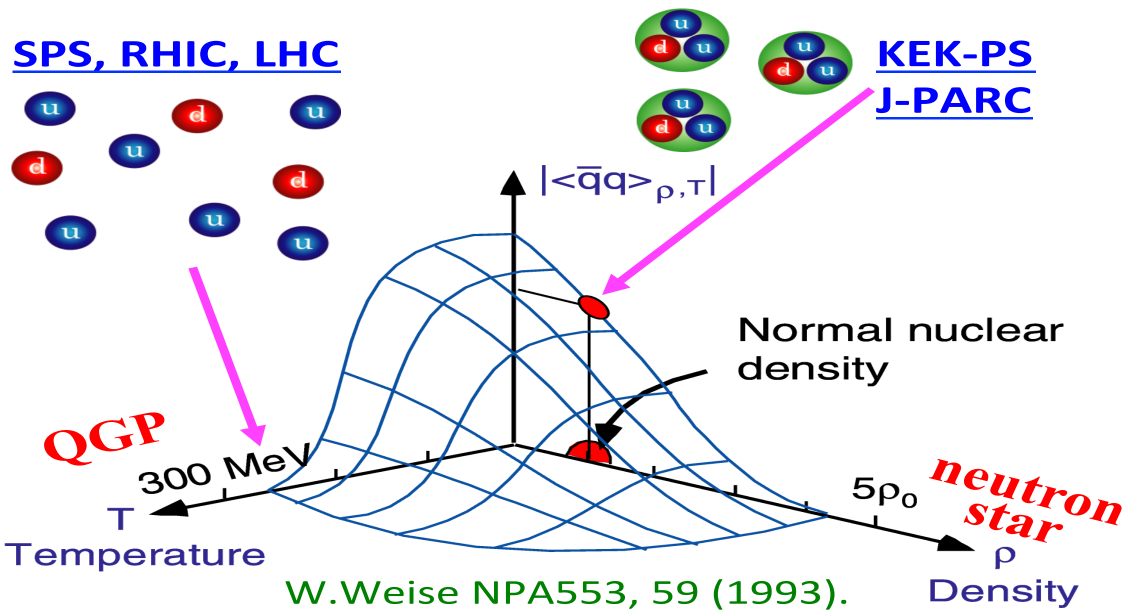
Lattice QCD may help us to understand the situation

Spontaneous breaking of chiral symmetry

- Spontaneous breaking of chiral symmetry is characterized by QCD order parameter

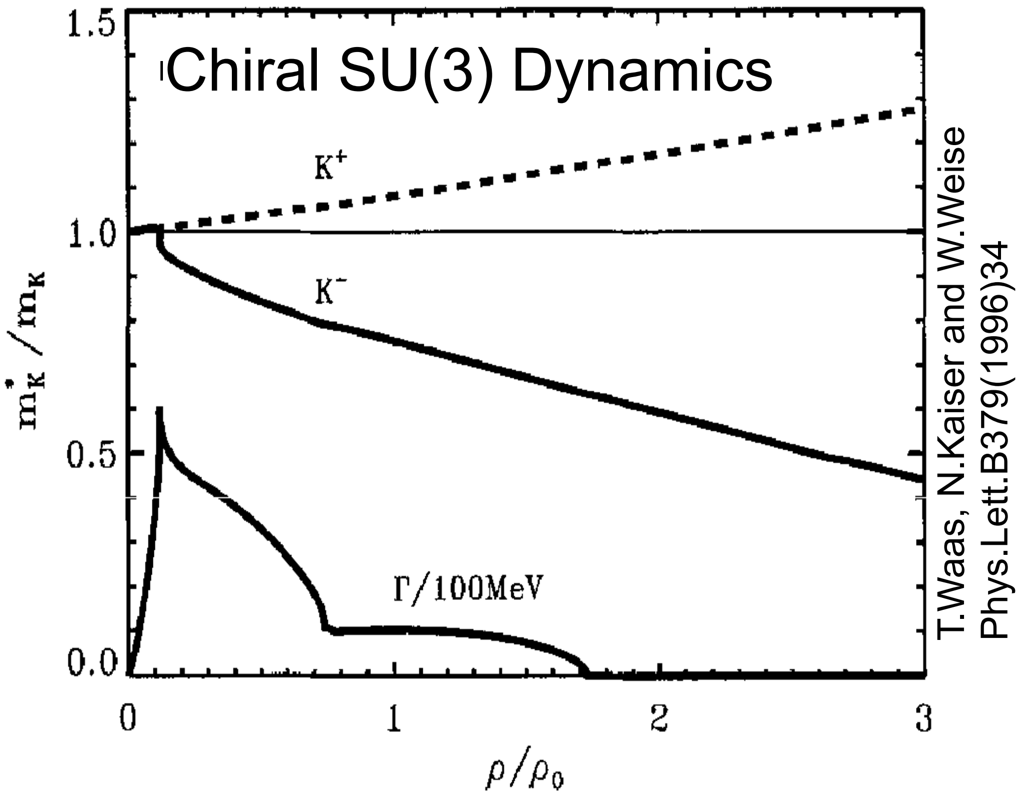
  i.e. $< \bar{u}u >=< \bar{d}d >=< \bar{s}s >\neq 0$

- The order parameter is changing as a function of its environmental temperature and density



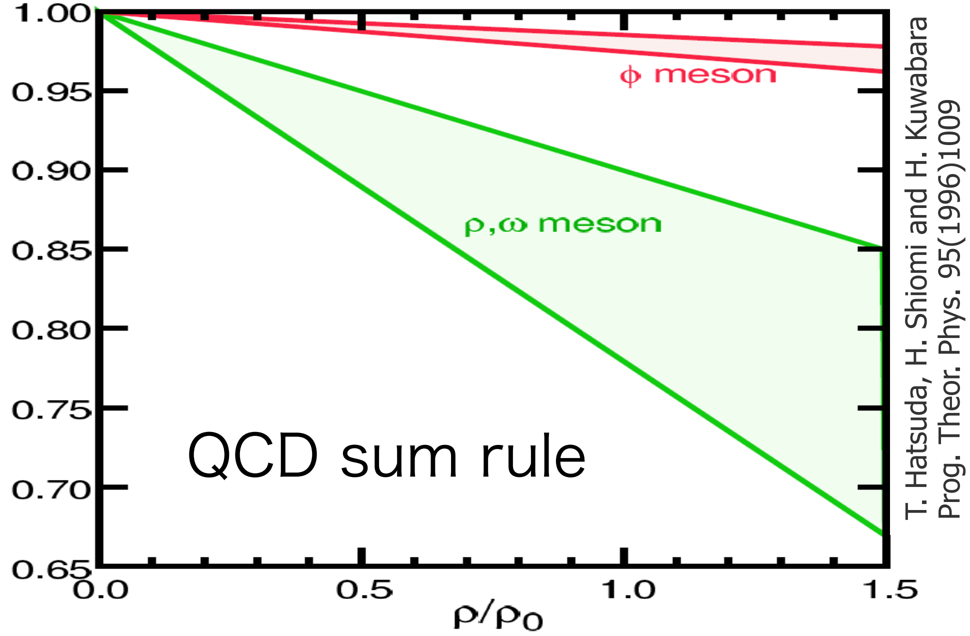
Meson property and chiral order parameter

Kaon in nuclear matter



vector meson

in nuclear matter



Meson property (c.f. mass) may change under high density environment

How to access meson property in nucleus

- Idea : embed meson in nuclear matter
  → property change on the embedded meson will tell us vacuum structure where meson exist

- Two possible approaches are exist.

  - producing meson in nucleus and reconstruct invariant mass via its decayed particles (c.f. ϕ, ω, ρ, J/ψ→e^+e^-, $\mu^+\mu^-$)

  - producing meson-nucleus bound state (medic-nucleus)

Invariant mass analysis

di-lepton measurement in heavy ion collisions

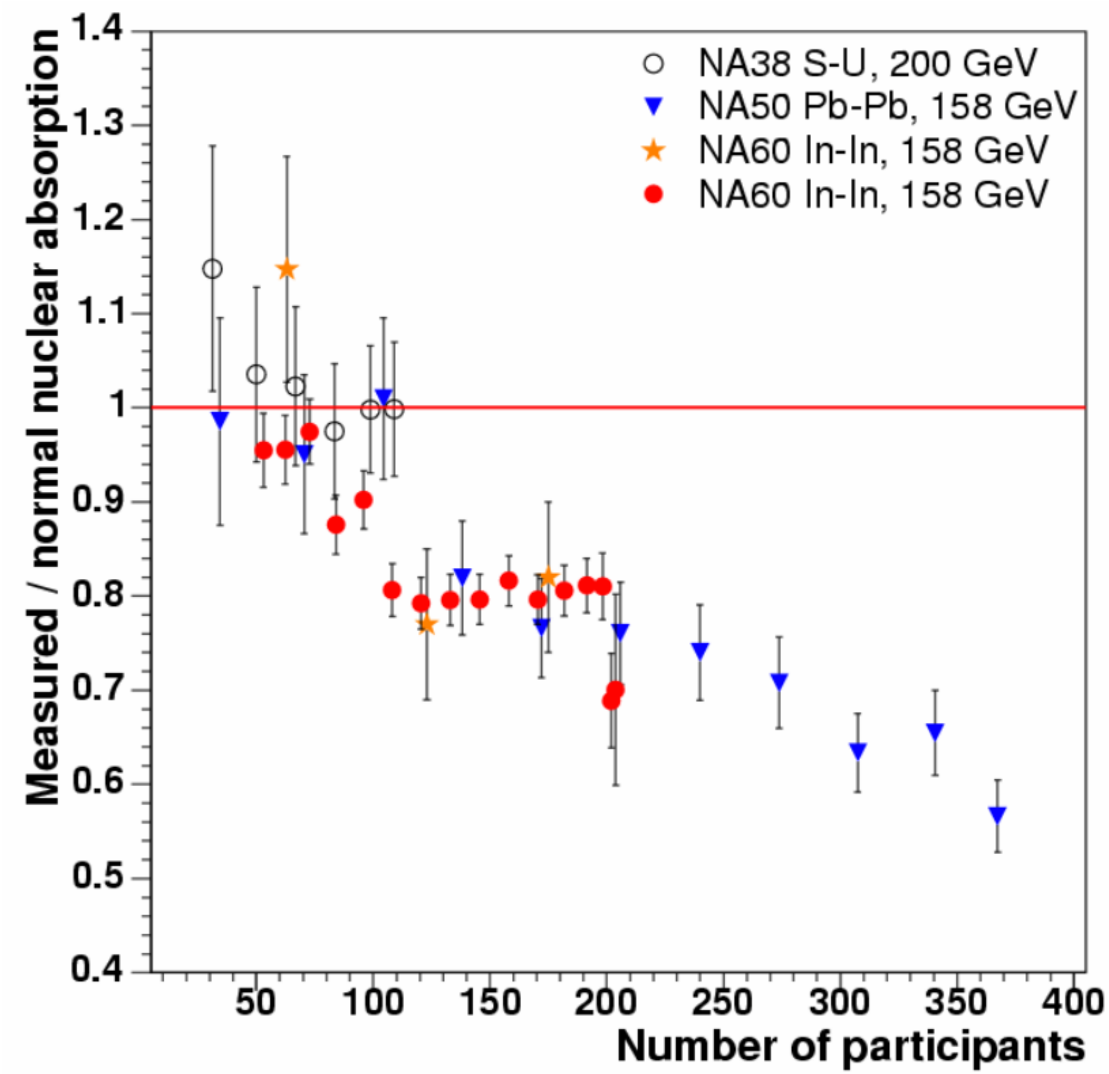
- di-electron and di-muon measurement
  in Sulfer nucleus on nucleus collisions
  CERN : NA34/NA45
  → low mass direction enhancement

- di-muon measurement in p-A to A-A collisions
  CERN : NA38/NA50/NA60
  → J/ψ suppression, ρ, ϕ etc.

- di-lepton measurement
  at PHENIX/RHIC, ALICE,CMS/LHC

Selected results from NA60

- J/ψ suppression in heavy ion collisions



collision centrality

Anomalous J/ψ suppression present in HI collisons

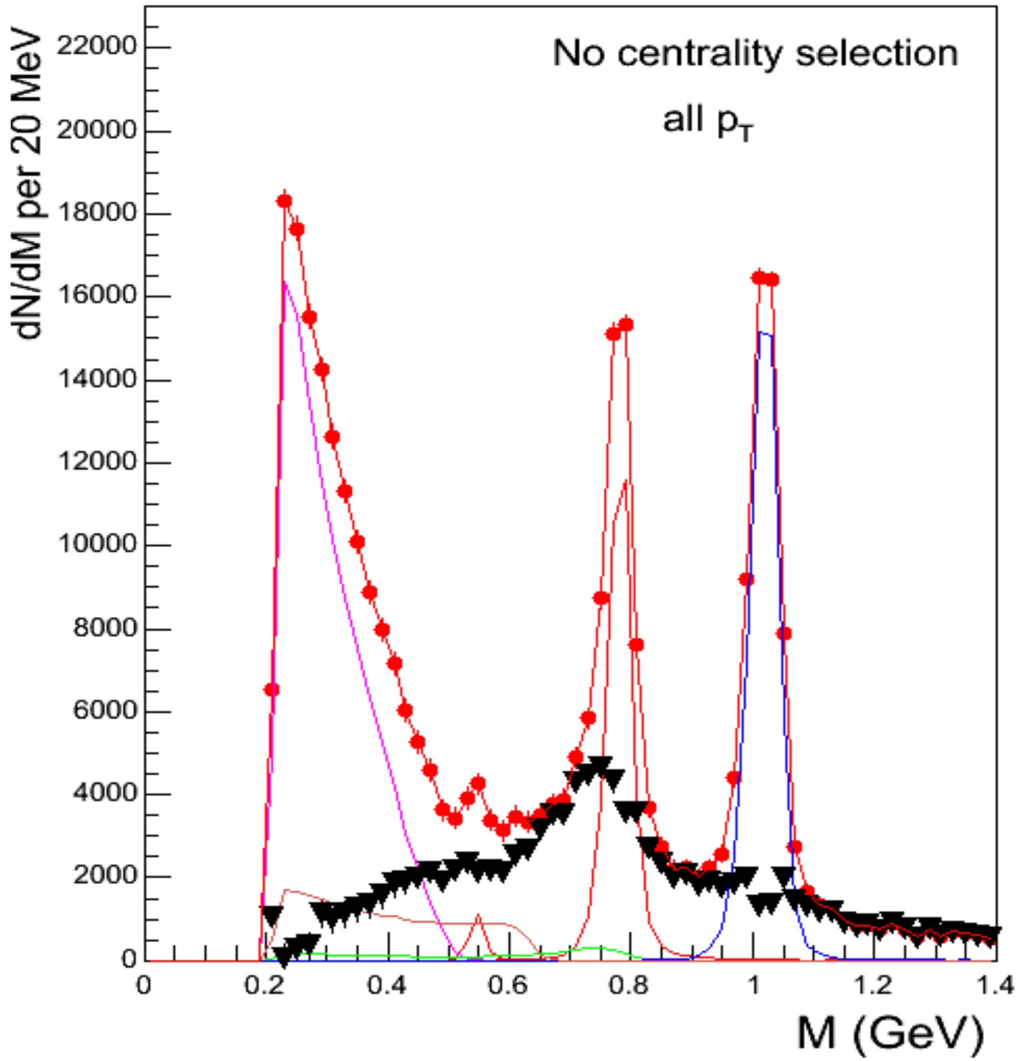
The following pattern is observed:

1) Onset of anomalous suppression between 80 < NPart < 100
2) Saturation at large NPart

Unexpected phenomena (vacuum property change) observed!

Selected results from NA60 (2)

- low mass dimuon spectra in high temperature matter



ω and ϕ meson are clearly identified

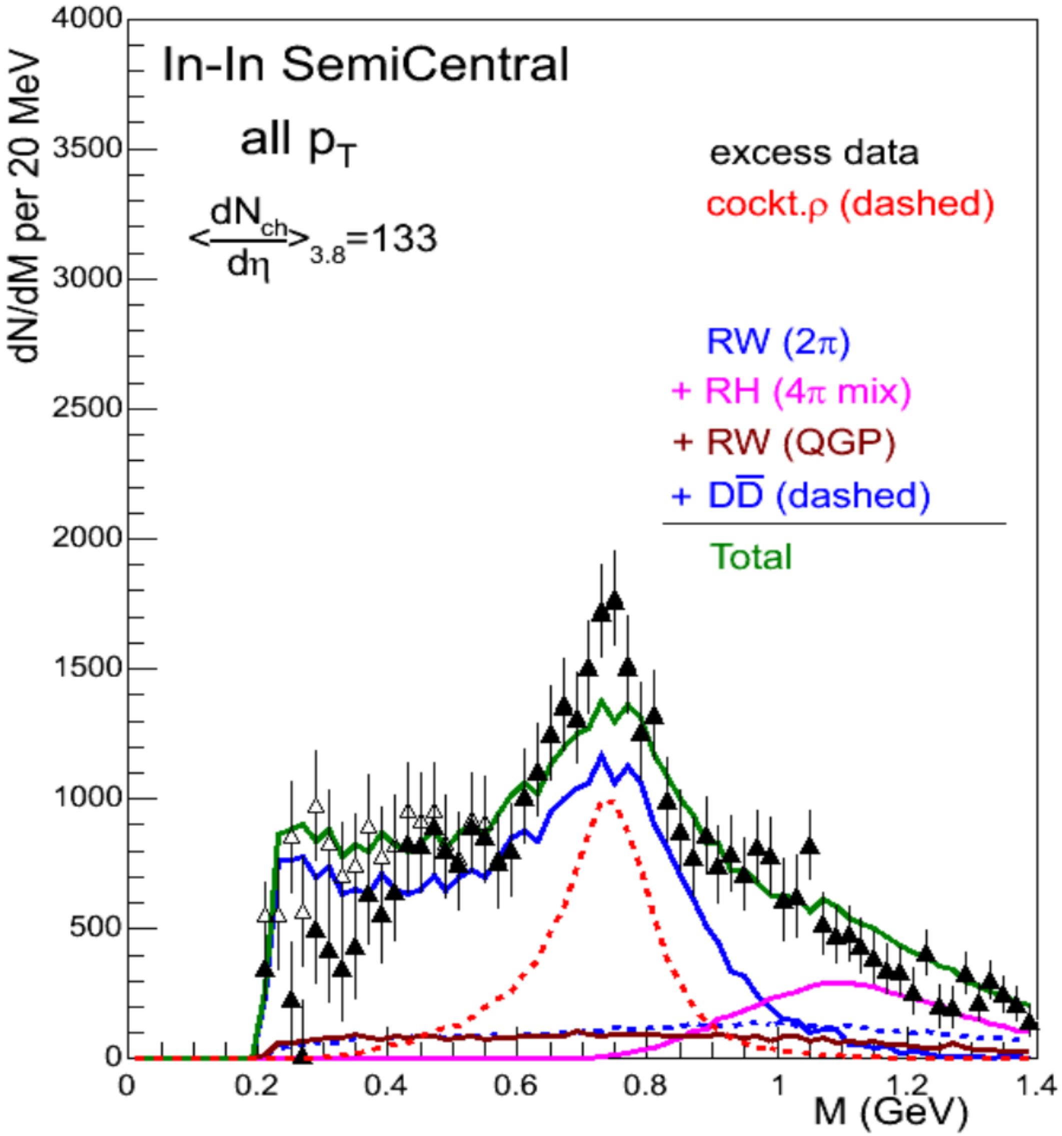
simple approach is used to subtract known sources (except the)

ω and φ yields fixed to get, after subtraction, a smooth underlying continuum

η: set upper limit by "saturating" the yield in the mass region 0.2–0.3 GeV leads to a lower limit for the excess at low mass

Selected results from NA60 (2)

- low mass dimuon spectra in high temperature matter

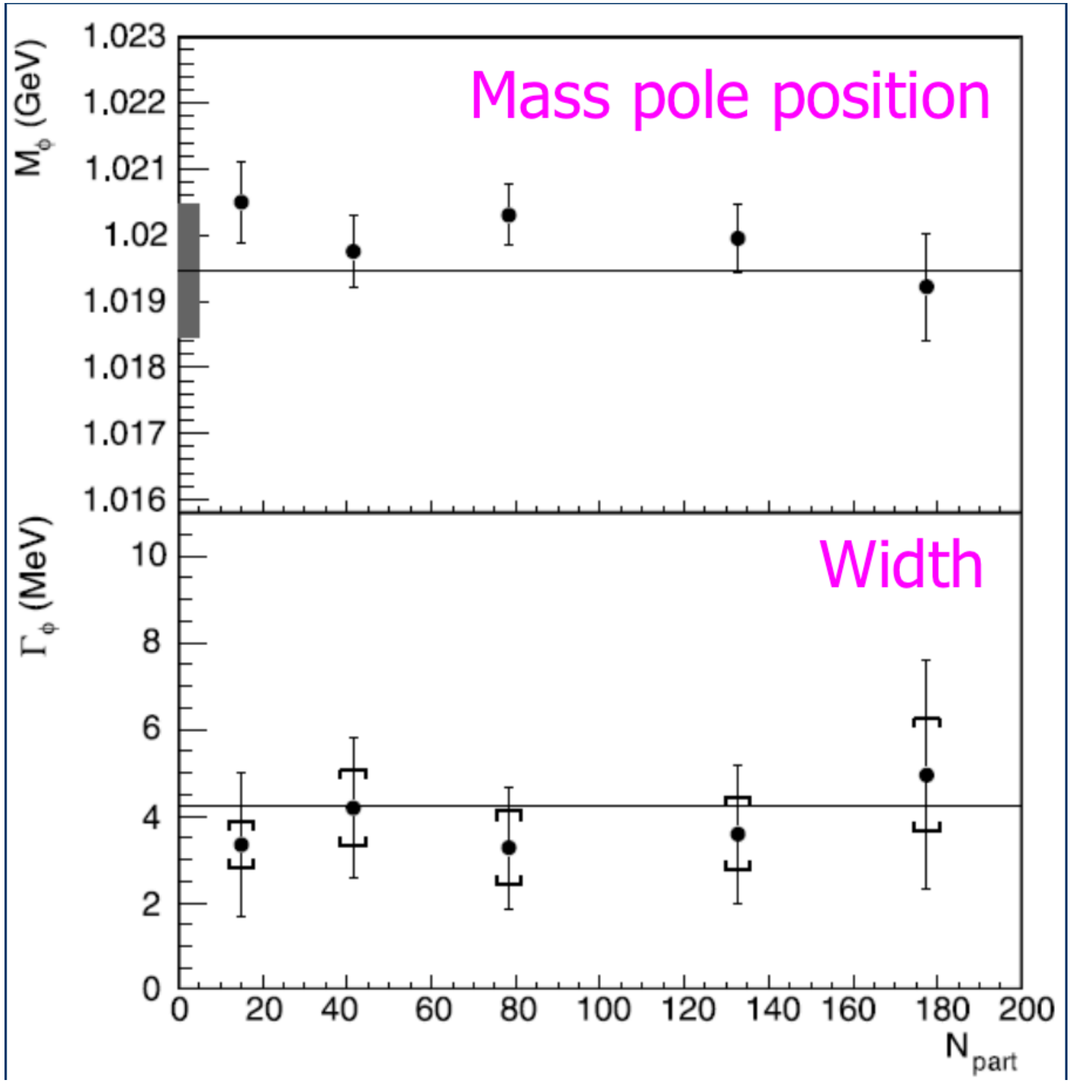


Excess spectra can be described very well with broadening of ρ meson!

No width mass shift is observed on ρ meson

Selected results from NA60 (2)

- ϕ meson



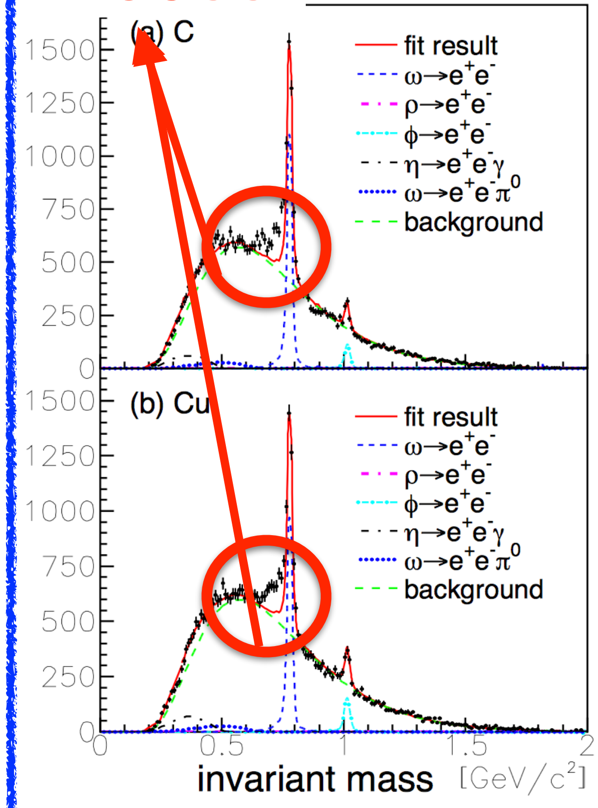
For the ϕ meson,
mass shift nor broadening
are not observed
(within detector resolution)

Normal nuclear matter density
i.e. p-A and γA collisions

KEK-PS/E325, SPring-8/LEPS, J-Lab/CLAS

ρ meson in pA and γ A collisions

Excess!

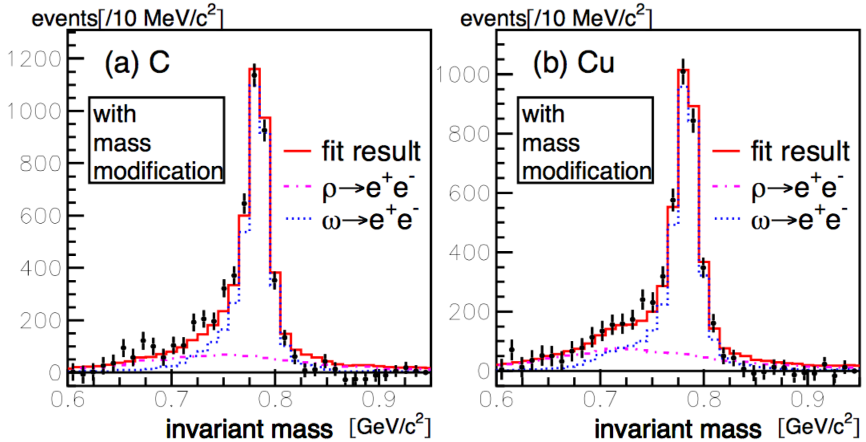


Phys. Rev. Lett. 96, 092301 (2006)

p-A

(KEK-PS/E325)

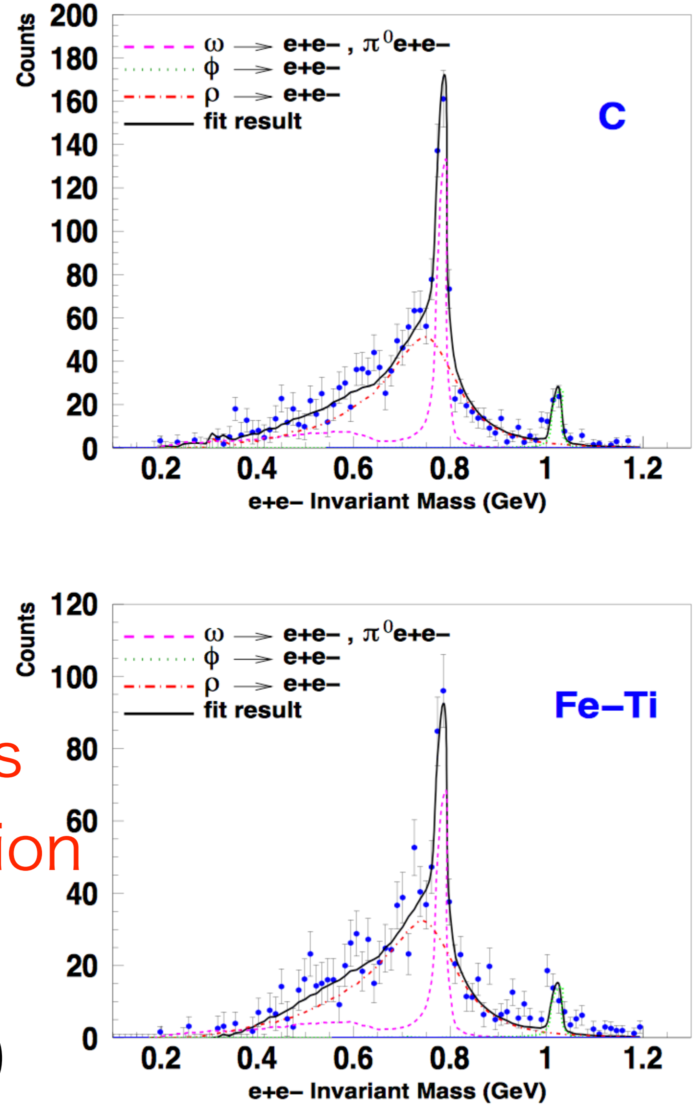
consistent with mass shift of ρ meson model



no mass modification

γ-A

(CLAS)



Phys.Rev.Lett.99:262302,2007

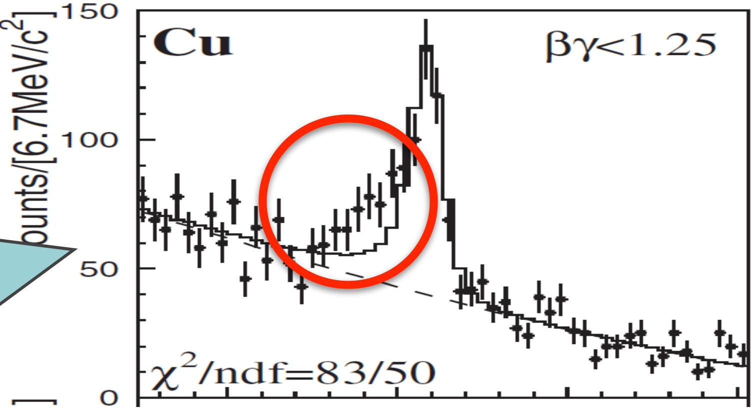
ϕ meson in normal nuclear matter

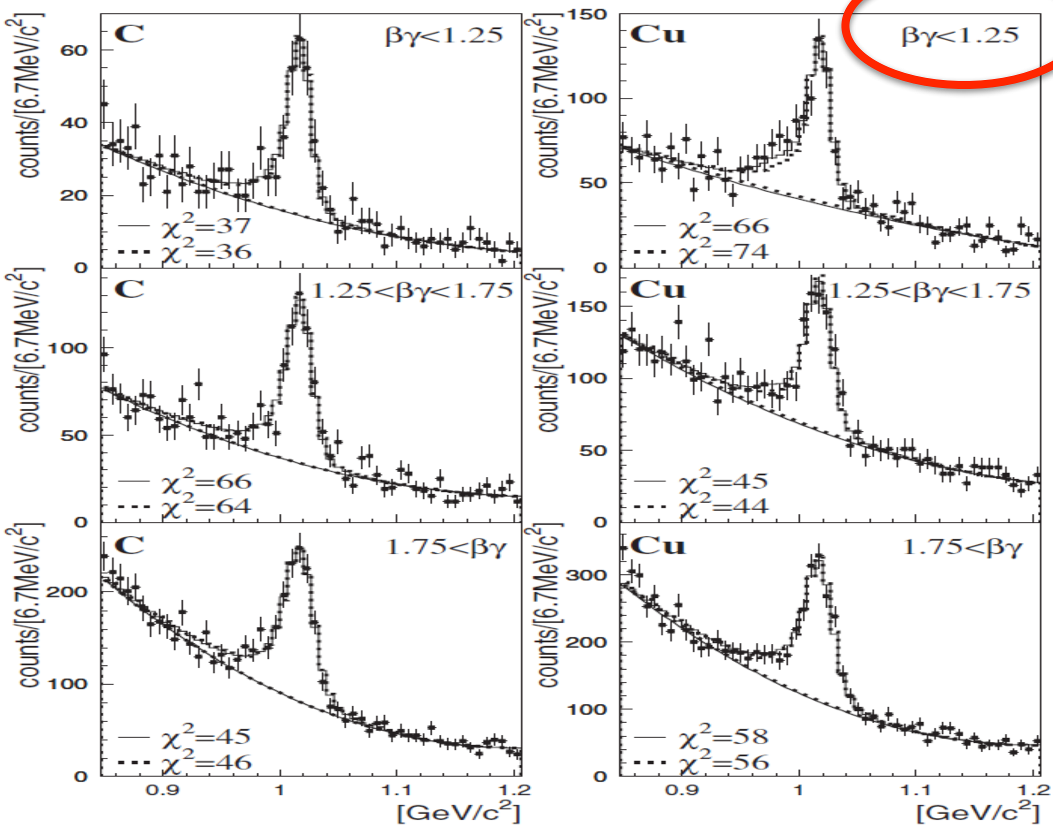
PRL **98,** 042501 (2007) PHYSICAL REVIEW LETTERS week ending 26 JANUARY 2007

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. Kand
M. Kitaguchi,[3] S. Mihara,[3,‡] K. Miwa,[3] T. Miyashita,[3] T. Murakami,[3] T. Nakura,[3] M. Naruki,[1] K. Ozawa,[4,‖] F. S
O. Sasaki,[2] M. Sekimoto,[2] T. Tabaru,[1] K. H. Tanaka,[2] M. Togawa,[3] S. Yamada,[3] S. Yokkaichi,[1] and Y. Yoshi

(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

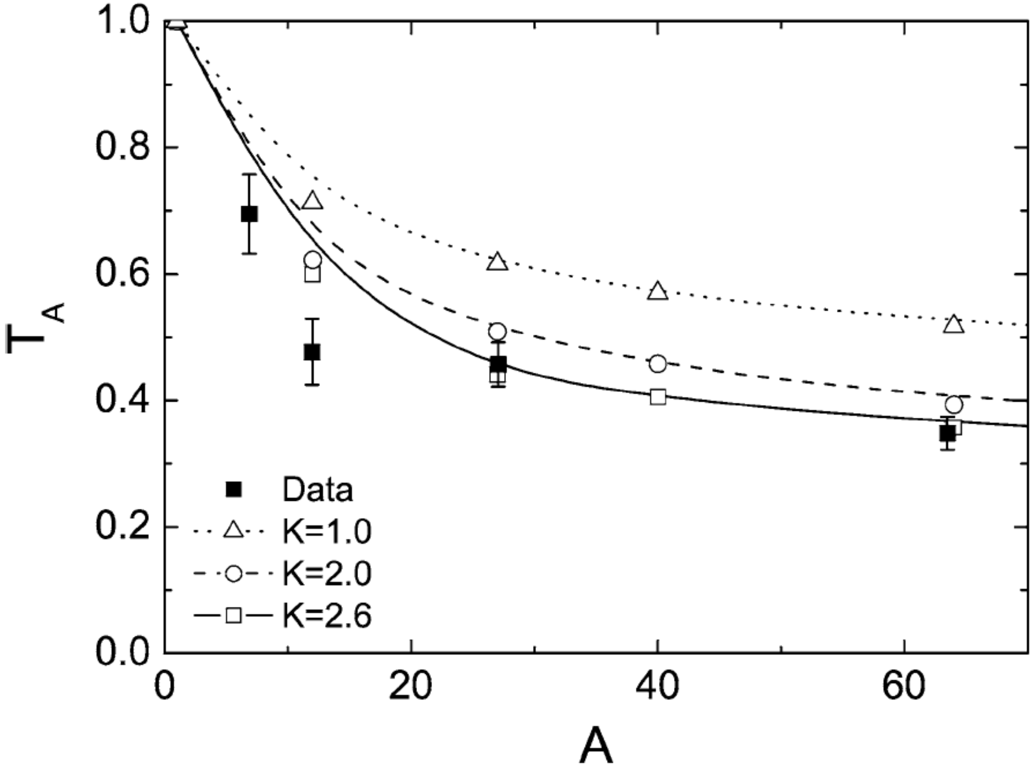
when only the slowly moving phi mesons with respect to the target nuclei were selected ($\beta\gamma_{\phi}<1.25$)

detail will be discussed in next talk

about ϕ meson decay width in nuclear media

can be accessible via Transparency ratio,

$T_A = \sigma_{\gamma A\text{-}\phi X} / A(\sigma_{\gamma p\text{-}\phi X})$,



NPA765(2006)188-196

- Data : PLB 608(2005)215
  $\gamma A \rightarrow \phi X$: Extracted $\sigma_{\phi N}$ =30 mb
- Analysis : NPA 765(2006)188
  $\sigma_{\phi N}$ expected (Theo.) ~10 mb
- discrepancy between $\sigma_{\phi N}$ measured and expected is explained by width broadening of ϕ in nuclear media by factor 16! ($\Gamma_{\text{in nucleus}}$ ~70 MeV)

$\sigma_{\phi N} \sim 10$ mb $\rightarrow$ $\lambda_{\text{interaction}} = 7.0$ fm

$\sigma_{\phi N} \sim 30$ mb $\rightarrow$ $\lambda_{\text{interaction}} = 3.5$ fm

Absorption?

even observed in γ d reaction

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Measurement of the incoherent $\gamma d \to \phi pn$ photoproduction near threshold

LEPS Collaboration

W.C. Chang[a,*], M. Miyabe[b], T. Nakano[c], D.S. Ahn[c,d], J.K. Ahn[d], H. Akimune[e], Y. Asano[f], S. Daté[g], H. Ejiri[c], H. Fujimura[h], M. Fujiwara[c,i], S. Fukui[j], S. Hasegawa[c], K. Hicks[k], K. Horie[c], T. Hotta[c], K. Imai[b], T. Ishikawa[h], T. Iwata[l], Y. Kato[c], H. Kawai[m], K. Kino[c], H. Kohri[c], N. Kumagai[g], S. Makino[n], T. Matsuda[o], T. Matsumura[p], N. Matsuoka[c], T. Mibe[c], M. Miyachi[q], N. Muramatsu[c,i], M. Niiyama[b], M. Nomachi[r], Y. Ohashi[g], H. Ohkuma[g], T. Ooba[m], D.S. Oshuev[a], C. Rangacharyulu[s], A. Sakaguchi[r], P.M. Shagin[t], Y. Shiino[m], H. Shimizu[h], Y. Sugaya[r], M. Sumihama[c], Y. Toi[u], H. Toyokawa[g], M. Uchida[u], A. Wakai[v], C.W. Wang[a], S.C. Wang[a], K. Yonehara[e], T. Yorita[c,g], M. Yoshimura[w], M. Yosoi[c], R.G.T. Zegers[x]

Contents lists available at ScienceDirect
Physics Letters B
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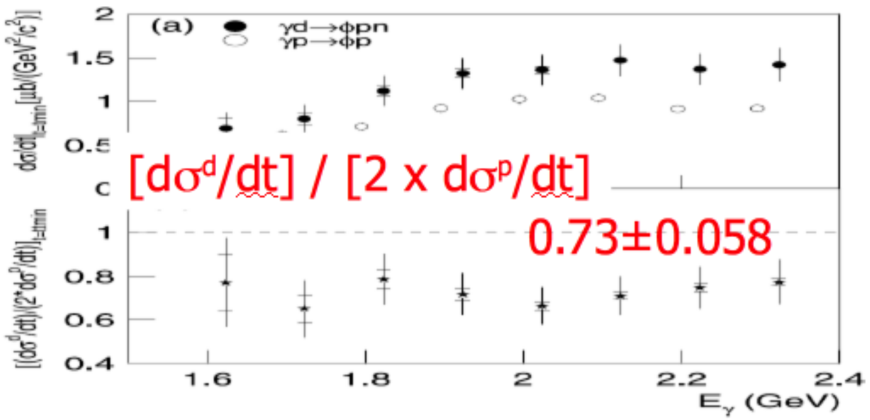
The extraction of ϕ–N total cross section from $d(\gamma, pK^+K^-)n$

CLAS Collaboration

X. Qian[a,*], W. Chen[a], H. Gao[a], K. Hicks[b], K. Kramer[a], J.M. Laget[c,d], T. Mibe[b], S. Stepanyan[d], D.J. Tedeschi[e], W. Xu[f], K.P. Adhikari[af], M. Amaryan[af], M. Anghinolfi[w], H. Baghdasaryan[am], J. Ball[c], M. Battaglieri[w], V. Batourine[d], I. Bedlinskiy[z], M. Bellis[k], A.S. Biselli[p,ag], C. Bookwalter[r], D. Branford[o], W.J. Briscoe[s], W.K. Brooks[al,d], V.D. Burkert[d], S.L. Careccia[af], D.S. Carman[d], P.L. Cole[u,d], P. Collins[h], V. Crede[r], A. D'Angelo[x,ai], A. Daniel[b], N. Dashyan[ao], R. De Vita[w], E. De Sanctis[v], A. Deur[d], B. Dey[k], S. Dhamija[q], R. Dickson[k], C. Djalali[e], G.E. Dodge[af], D. Doughty[m,d], R. Dupre[g], P. Eugenio[r], G. Fedotov[aj],



Experiment : $\gamma d \to \phi X$
Extracted ϕN cross section
$\sigma_{\phi N}$ = 20 mb
Again $\sigma_{\phi N}$ Expected,
$\sigma_{\phi N}$ = 11 mb (upper limit)
How to explain this discrepancy?
Again width broadening of ϕ meson in nuclear matter even on deuteron?

ϕ meson absorption? by nuclear matter?
even with deuteron (single nucleon??)

Open question and puzzles

- The mass shift is not seen in high temperature matte? But width broadening are observed

- Mass shift observed in p-A collisions, but not in γ-A collisions

How do we understand those information consistently?

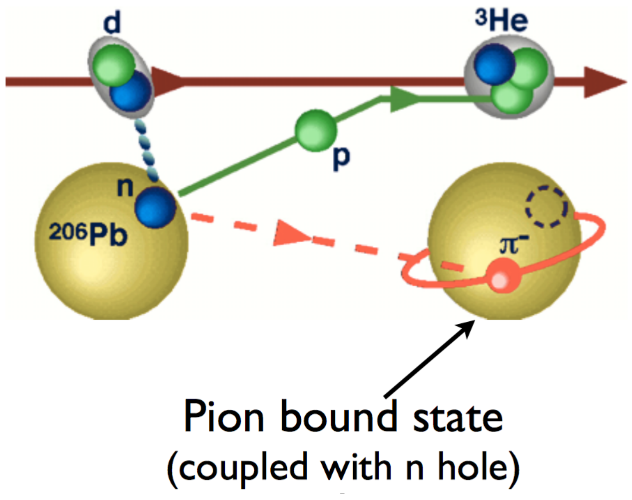
Indeed we need new experimental data with high precession

Another way to access the information
about meson property in nuclear matter

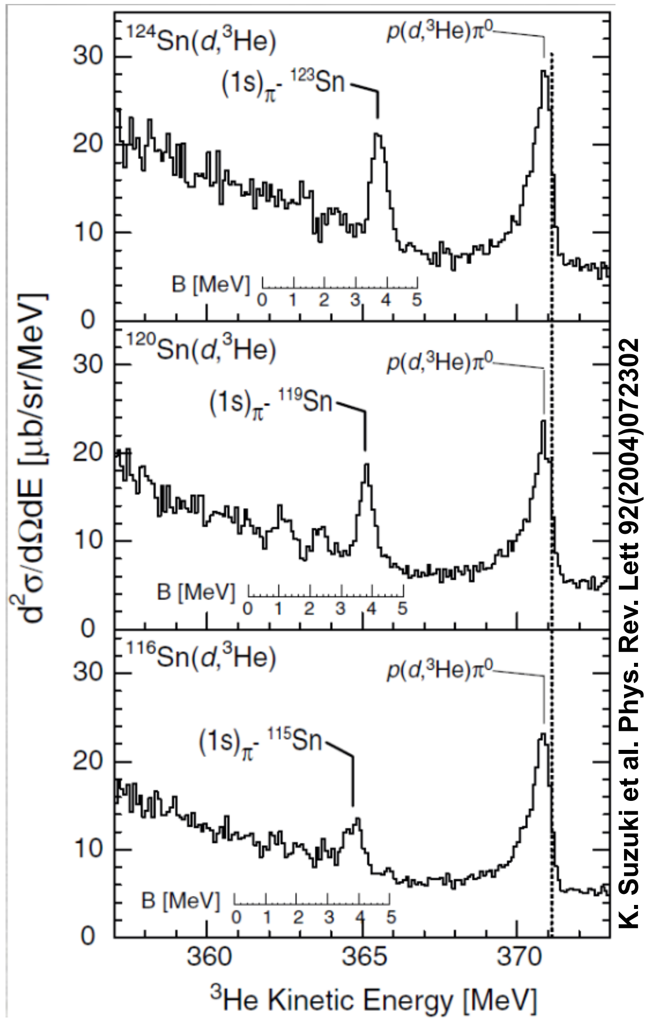
mesic-nucleus

How to produce meson nucleus bound state?

- hint : pionic atom formation experiment performed at GSI, RIBF
- producing pion at rest respect to target nucleus for this case using (d,^{3}He) reaction



- slow pion will be captured via nucleus
- Formation will be identified via missing mass analysis
  → if bound state formed peak structure in missing mass spectra will be appeared



masic-nucleus formation experiment at J-PARC

- Kaonic nucleus :　via 3He(K-,n) and　(π,K) reaction

  J-PARC E15　,　J-PARC E27

- ω mesic nucleus :　via　(π,n) reaction

  J-PARC E26

- ϕ mesic nucleus :　via　pbar+p→$\phi\phi$ in nucleus

  J-PARC E29

- η mesic nucleus :　via　(π,n)

  J-PARC LoI

Hadron physics performed or planed at J-PARC

E15/E31

Kaonic-nucleus

Λ(1405)

Kaon-nucleon interaction

Detail will be discussed this afternoon PM-13-PM2

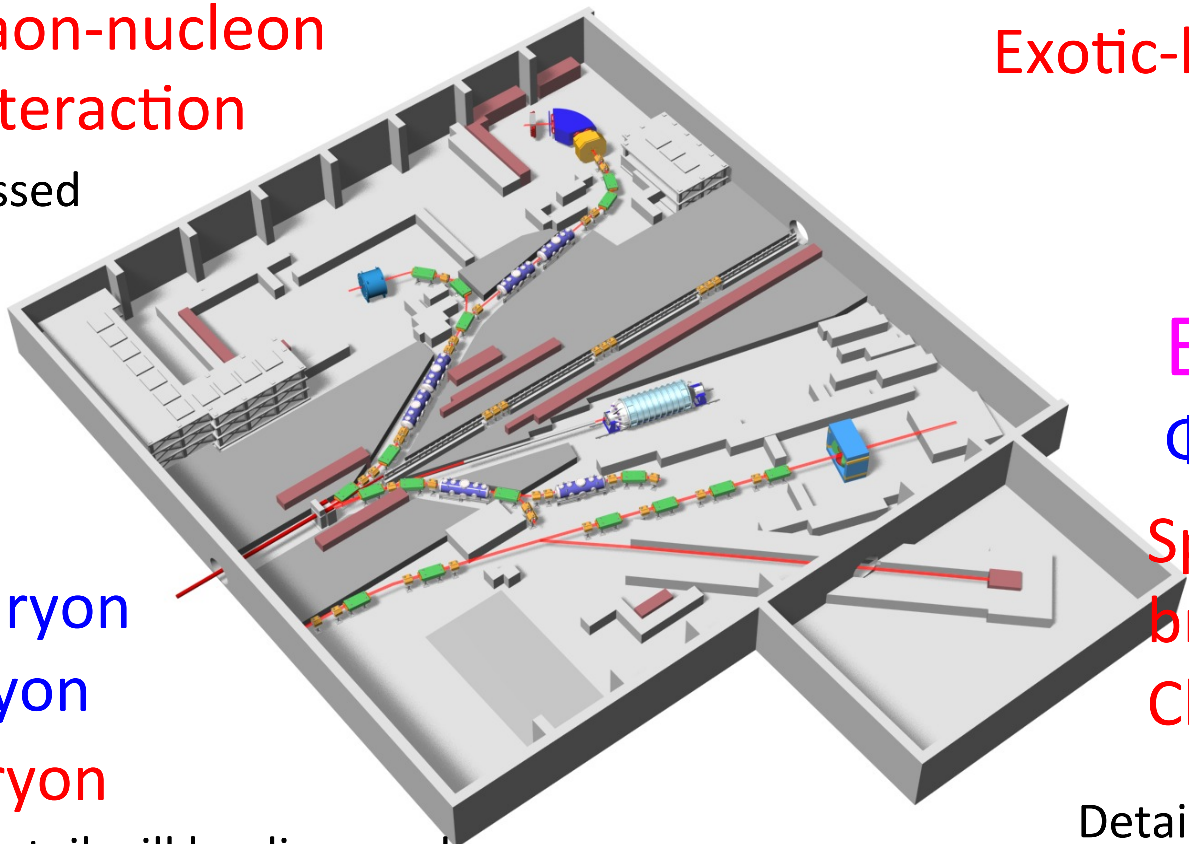
E27

Kaonic-nucleus

E19

Search for Pentaquark

Exotic-baryon



E16/E29

Φ in nucleus

Spontaneous breaking of Chiral symmetry

Detail will be discussed in PHS-15-PM1

E50

Charmed baryon

Strange baryon

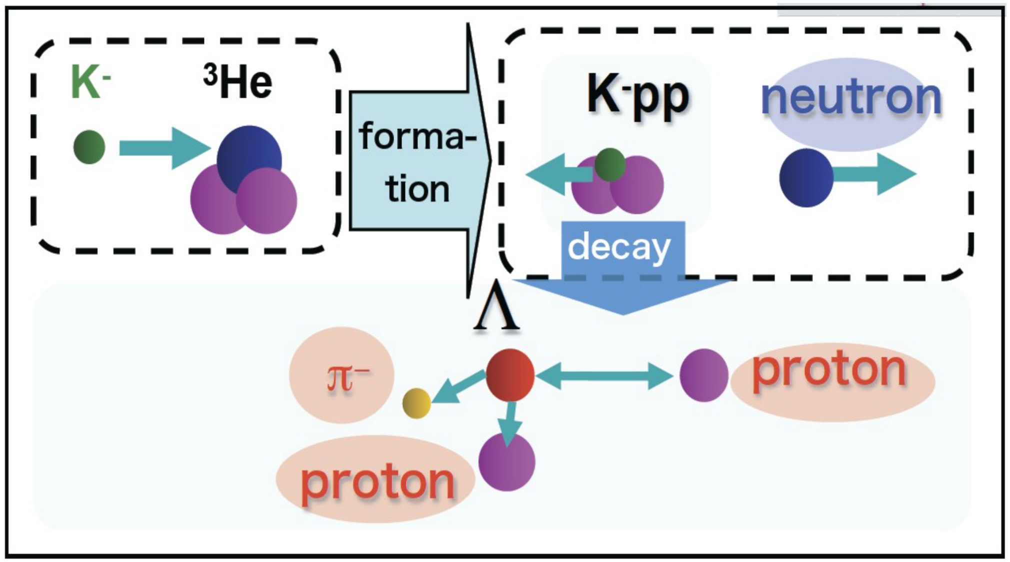
Exotic-baryon

Detail will be discussed in PHS-15-PM1

J-PARC E15

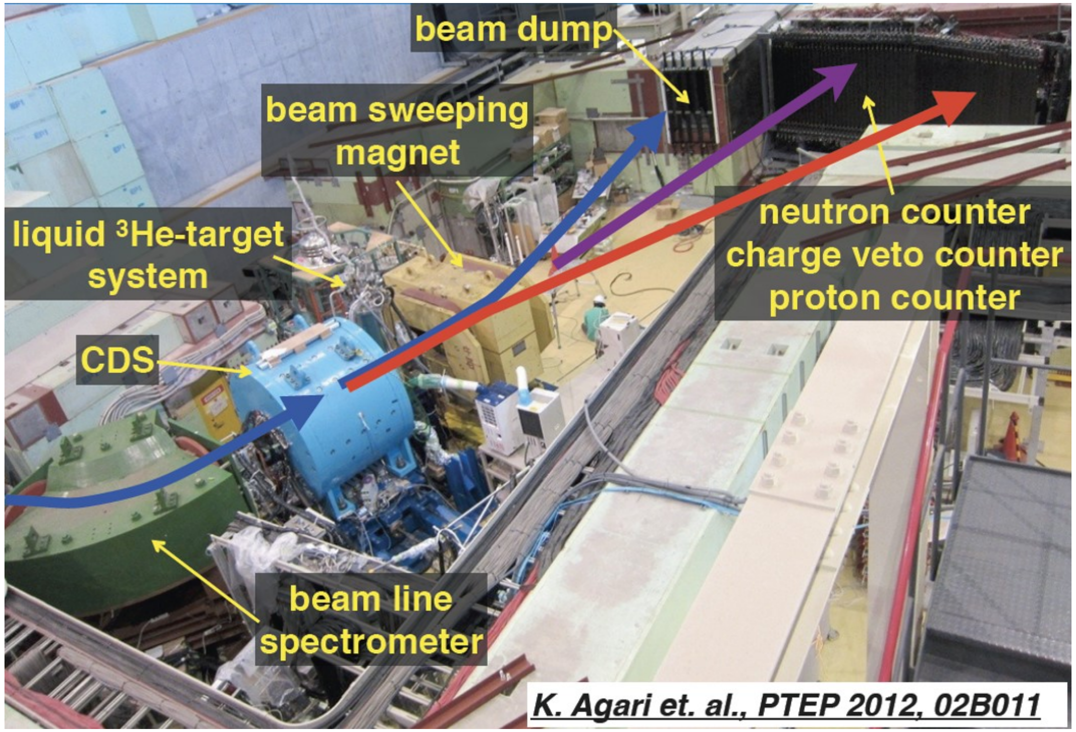
Search for K-pp bound state

- K-3He → "ppK-" + n using 1 GeV/c K- beam



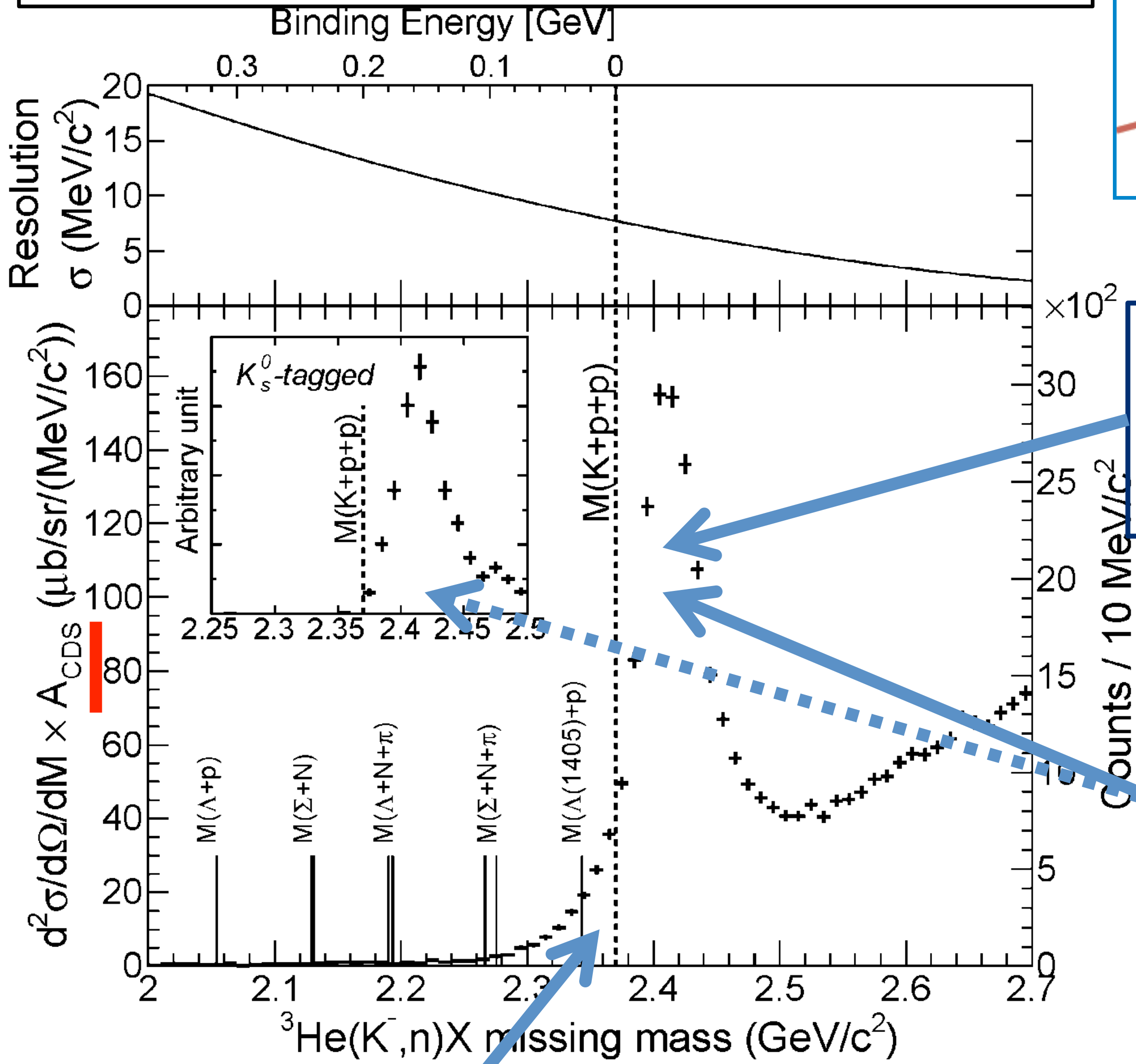
- 1st physics data taking completed on May 2014

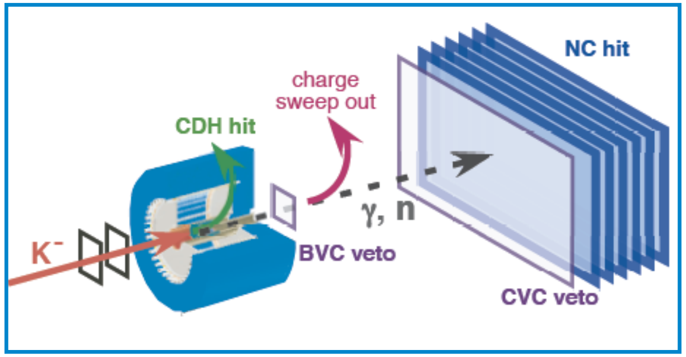
- 2nd physics run planed very soon (April 2015 -)



1st physics results

Semi-Inclusive Spectrum





Quasi Elastic

$K^- + {}^3He \rightarrow K^- + n + p_s + p_s$

$d\sigma/d\Omega_{\theta=0deg}$ ~ 6mb/sr

and

Charge-Exchange

$K^- + {}^3He \rightarrow K^0 + n + d_s$

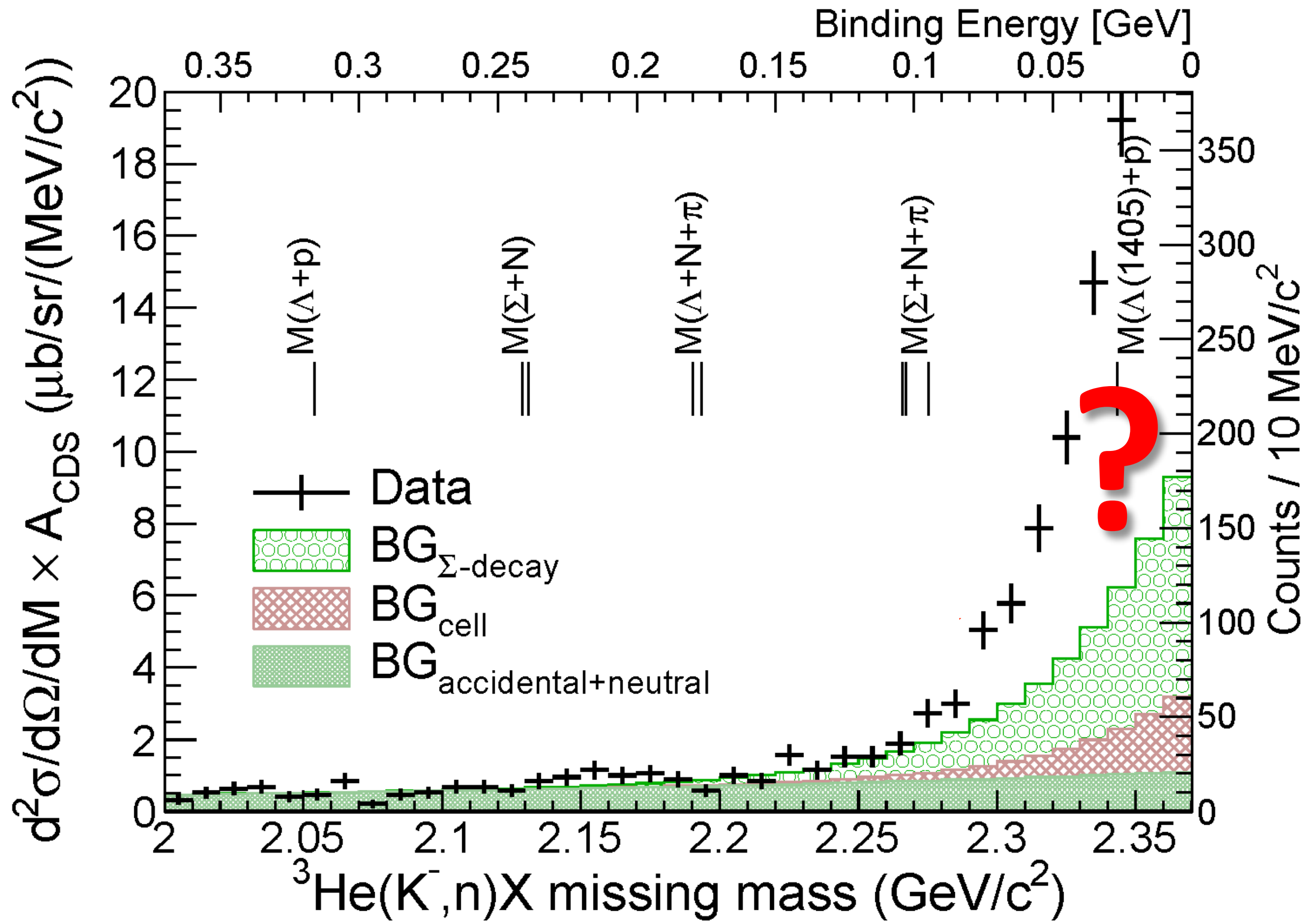
$K^0 \rightarrow \pi^+ + \pi^-$

$d\sigma/d\Omega_{\theta=0deg}$ ~ 11mb/sr

The tail structure is not due to “the detector resolution”

1st physics results

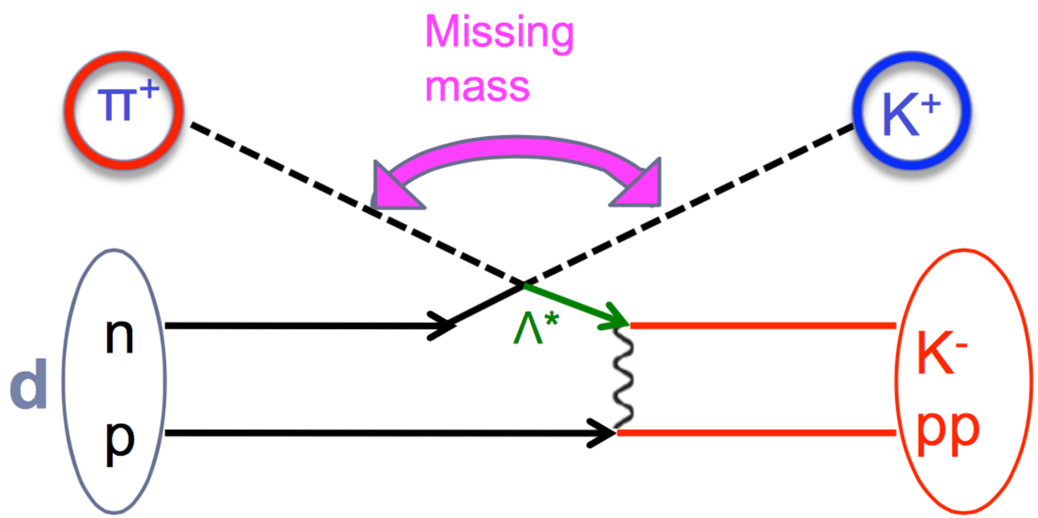
Spectrum below the Threshold

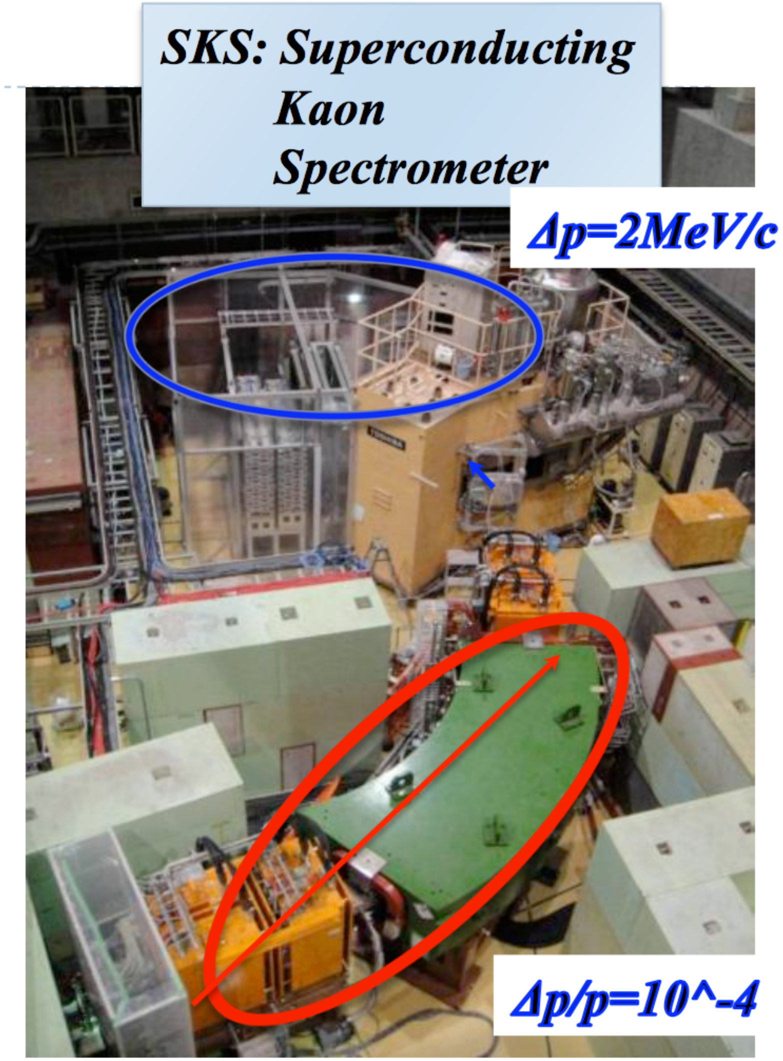


- No significant bump-structure in the deep-binding region
- Statistically significant excess just below the threshold

J-PARC E27

- Search for K-pp bound state via (π,K) reaction on deuteron





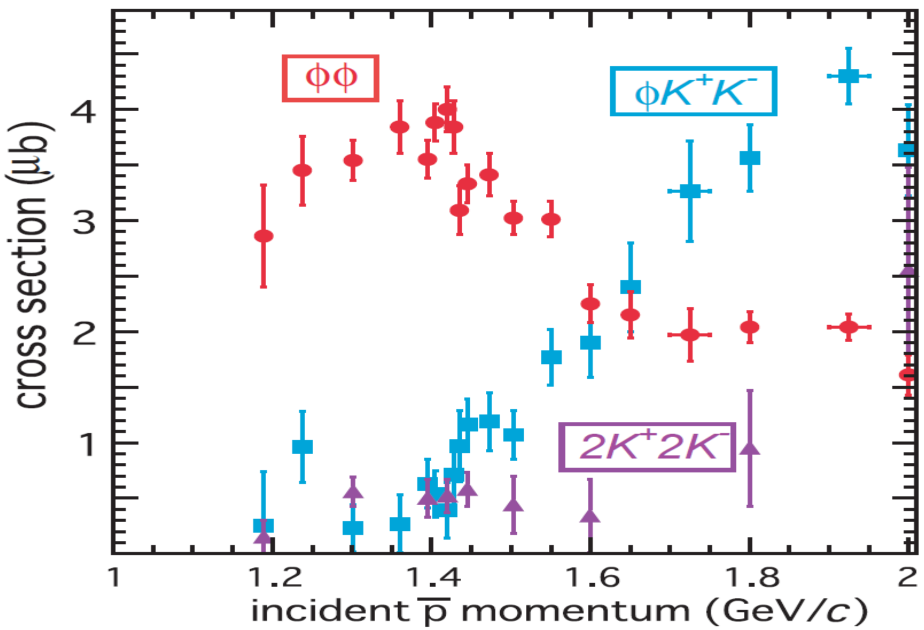
Missing mass spectroscopy

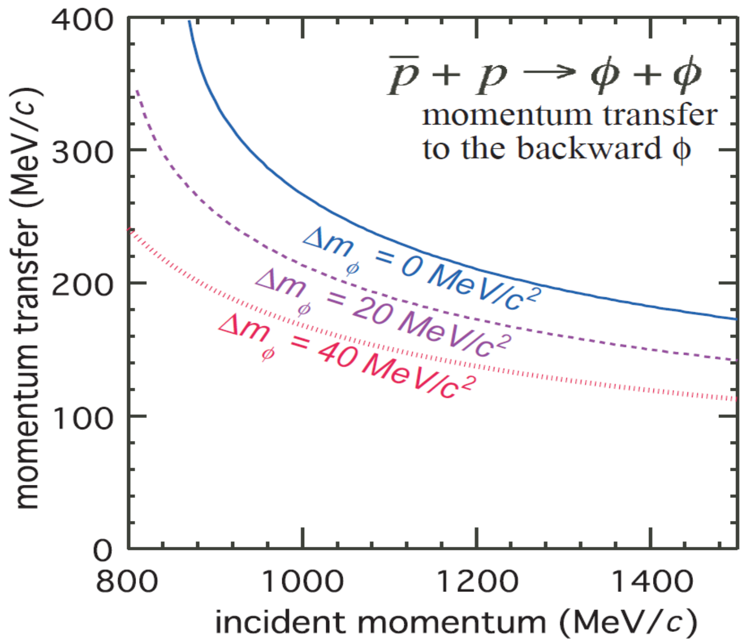
ΔM = 2.5MeV

Search for
ϕ meson bound state

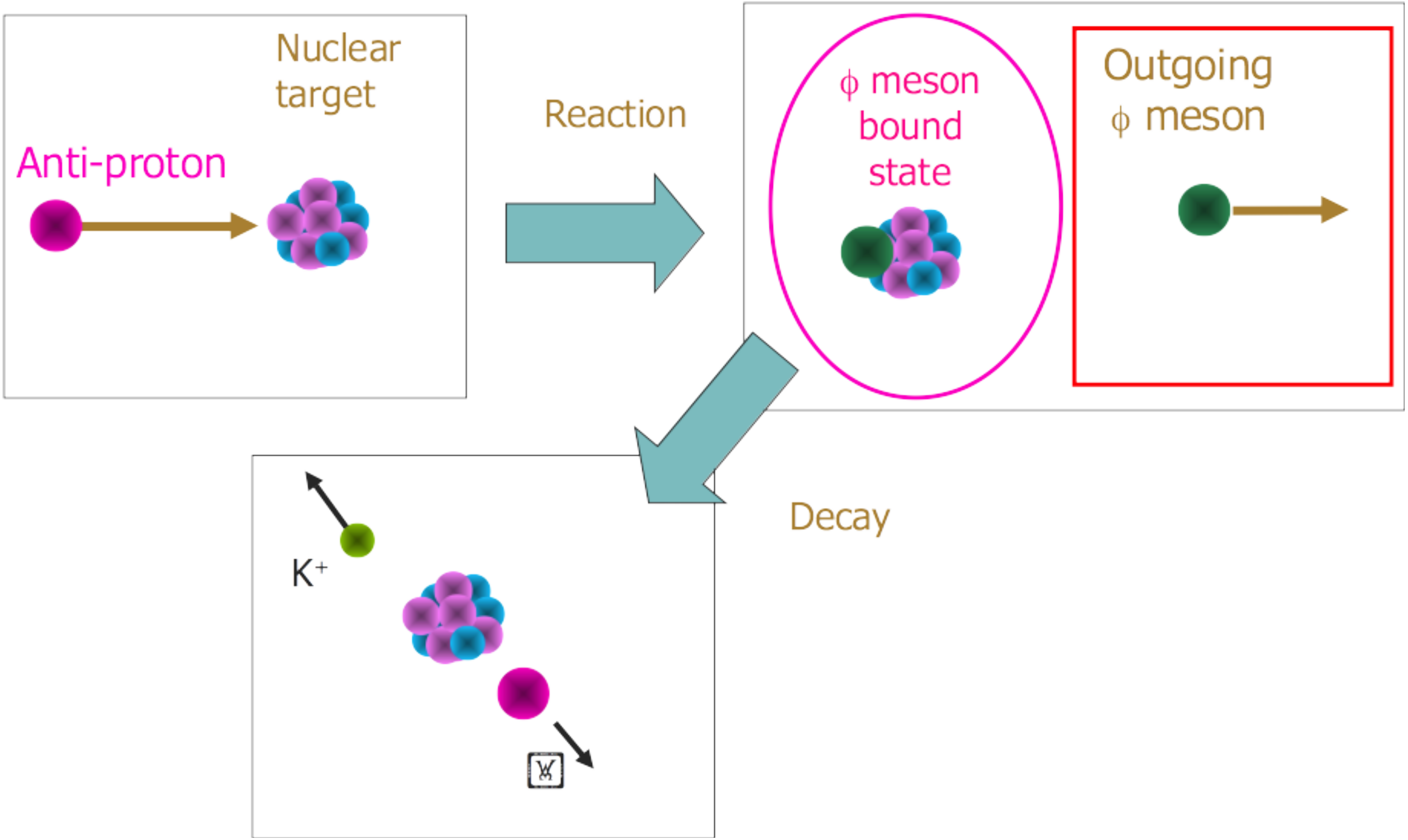
To produce ϕ meson bound state,
it is essential to producing slowly moving ϕ meson

pbar-p $\rightarrow \phi\,\phi$ reaction will be a best candidate
(1) relatively large cross section
(2) only produce slowly moving ϕ meson





Idea to produce ϕ meson bound state



$$\overline{p} + {}^{A+1}_{Z+1}\mathrm{X}' \rightarrow \{\phi\ {}^{A}_{Z}\mathrm{X}\} + \phi$$

Search for ϕ meson bound state

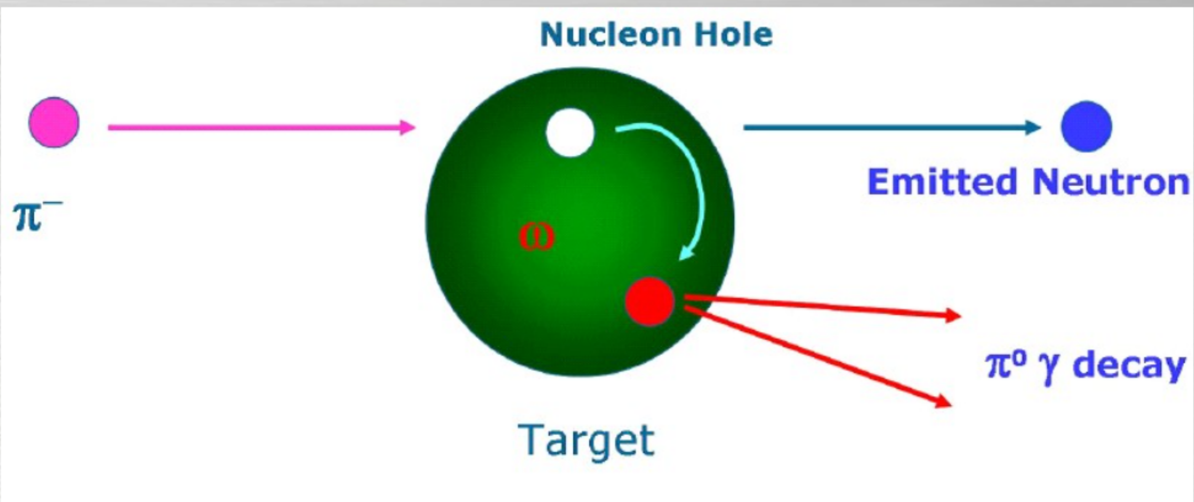
- If ϕ-N interaction is attractive enough,
  we will be able to detect signal of bound state.

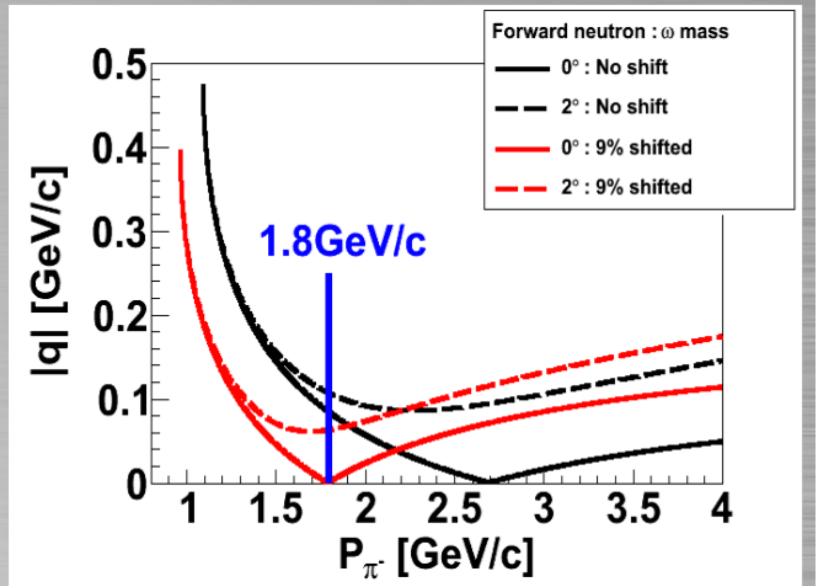
- need strong antiproton beam (0.8 ~ 1.1 GeV/c)
  → there are available at J-PARC

- preparation for the concrete proposal to ask stage-2 approval is under the way

ω meson in nucleus

- J-PARC E26 experiment
- 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





Mesic nucleus

- So far, only clear results are coming out from pion-nucleus system, a.k.a pionic-atom.
- However, new hints appeared in Kaon sector. (Kaon nucleus bound state)
- Other possibilities of mesic nuclear system are planed to explored at J-PARC.

  i.e. search for ω, ϕ, η meson bound state

Once mesic-nucleus system is identified,
we can start to investigate interaction between
meson and nucleus

What will come next?

- high momentum beam line will open new door
  for the hadron physics at J-PARC

- It is “charm meson / hidden charm meson” in nuclear matter

- For example,
  D meson-nucleus
  J/ψ-nucleaus bound state

- Problem is “it is not clear how to measure”.
  Because, to produce charm quark,
  we need high energy beam
  $\rightarrow$ produced charmonium moving very fast respect to nucleus

One possibility : using anti-proton

Just concentrate on J/ψ production using

pbar-p $\rightarrow$J/ψ channel (only J/ψ produced!)

This channel. It is not necessary to taking

effect of feed down into account

Very well known production cross section

(~ 311 nb for pbar-p $\rightarrow$J/ψ $\rightarrow \mu\,\mu$ on pole energy

where beam momentum of anti-p is 4.07 GeV/c)

Advantage (?) :

Antiproton will absorbed on the surface of nucleus

i.e. Produced J/ψ will penetrate through nucleus

Toward J/ψ nucleus bound state

Once $\sigma_{J/\psi\text{-}N}$ determined clearly, more accurate evaluation about existence for J/ψ bound state will be possible.

The lesson we learned from light meson nuclear bound state formation experiment,
producing slow momentum J/ψ production is essential

However, "how to produce slow J/ψ ?" is not clear.

Momentum for J/ψ on pbar-p $\rightarrow$ J/ψ is ~ 4.07 GeV/c
which is too large to produce nuclear bound state?

We need to produce J/ψ with momentum
~ a few hundred MeV/c

Slow J/ψ production

We will be able to use reaction

$$\text{pbar} + {}^4\text{He} \rightarrow J/\psi + {}^3\text{He}$$

"^{3}He" emitted forward direction

At production threshold,

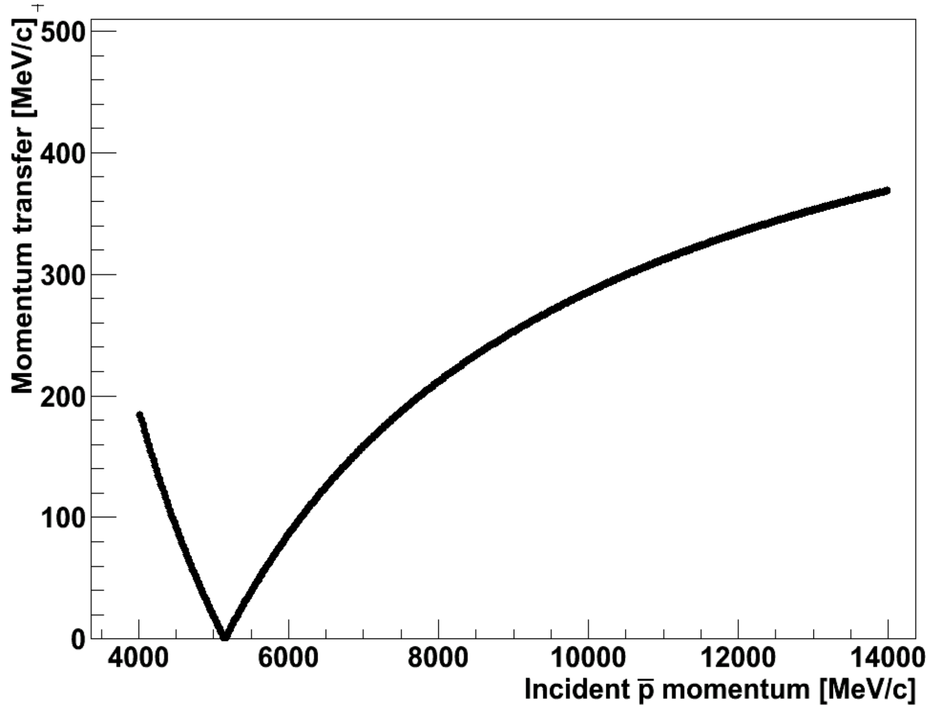
i.e. p=4.07 GeV/c,

momentum for J/ψ

will be 200 MeV/c.

(marginal momentum

to produce bound state)



Problem is

"no one knows the cross section for the reaction"

Summary

- investigation on meson property in nuclear media is one of the hot topics on the physics program at J-PARC
  - via “invariant mass analysis” and “mesic-nucleus”
- Physics data taking at J-PARC will be resumed soon, therefore we will have new results with in a few years
- High momentum beam line will open new opportunities → hadron physics with charm quark
- Close and intensive discussions between theorists and experimentalist are needed (like this workshop)

  → what we need to measure and what we can learn from it